GEOLOGICAL SURVEY OF THE UNITED KINGDOM.

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MEMOIRS

OF THE

GEOLOGICAL SURVEY OF GREAT BRITAIN,

AND OF THE

MUSEUM OF PRACTICAL GEOLOGY

IN

LONDON.

VOLUME THE SECOND.

PART II.

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VOL II.—PART II.

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MEMOIRS

OF THE

GEOLOGICAL SURVEY

OF

GREAT BRITAIN, &c.

VOL. II.—PART II.

On the Vegetation of the Carboniferous Period, as compared with that of the present day. By Dr. Joseph Hooker, Botanist to the Geological Survey of the United Kingdom.

There are few persons who have devoted any time to the study of fossil plants, especially those of the coal formation, and have not been particularly interrogated on the value of their results, compared with those derivable from the investigation of animal remains. What that value may be, is daily asked of the naturalist, while in the field, by the uninitiated yet curious looker-on, who eagerly offers his aid as a collector in exchange for information upon the materials he gives or offers to procure. It is no less frequently proposed by the young geologist, who, though skilled in seizing the characters presented by a comparatively indestructible shell or bone, is at a loss to appreciate those afforded by the always compressed and more or less mutilated fragments of what were originally perishable plants.

It is with a view of instructing such enquirers that the following introductory observations are thrown together. Relating exclusively to the more obvious features of that formation which conspicuously abounds in fossil vegetables, to their most prominent characters, and to the botanical value of those features only, they can have no claim upon the attention of the experienced palæontologist. They are little more than the first impressions received by a naturalist, who, having been almost exclusively occupied with an existing Flora, is called upon to contrast with it the fragmentary remains of another Flora, whose species are, without an exception, different from those now living, which represent in part the vegetation of a period indefinitely antecedent to the present, and have been succeeded by still other plants, equally diverse from both, and which have likewise perished.

From the very outset it must be borne in mind, that whatever light future investigations of hitherto unexplored coal-fields may throw upon this most difficult subject, we can never hope thereby to arrive at any great amount of precision in determining the species of vegetable remains, nor to ascertain the degree of value due to the presence or absence of certain forms, such as the animal kingdom so conspicuously affords. Still less can we expect that they will prove equally appreciable indices of the climate and other physical features of that portion of the surface of the globe upon which they once flourished.

The great extent of the vegetable kingdom is hardly to be appreciated except by the professed botanist; and he must be an advanced student who knows as much of its main features as he may acquire of the animal creation during the course of an ordinary education. Every one, for example, is familiar with the divisions of the class Animalia into beasts, birds, fish, reptiles, shells, &c.; but much study is required to attain an equal amount of acquaintance with the parallel divisions of plants into exogenous, endogenous, &c. The technical terms, too, employed in the one case are, very many of them, universally intelligible; whilst the majority of those applied to the more conspicuous organs of plants must be acquired by a special study. Lastly, the external organs of vegetables, and especially such as are generally available in the fossil state, are not the same guides to the affinity of the objects themselves, to their habits, or to the nature of the area they occupied, which the similarly conspicuous organs of animals are. Thus, were fossil vegetables much more perfect than they are, the information to be derived from their study will never hold a rank of equal importance to the geologist with that afforded by animal remains.

It is partly owing to these circumstances that the study has been comparatively neglected; partly also because a far more comprehensive knowledge of the existing forms of plants is required to make any progress in fossil botany, than of recent zoology to advance equally in palæontology; for, whilst an acquaintance with a single class of animals (the shells for instance) enables the student to understand and distinguish whole formations, he cannot, without being somewhat conversant with all classes of living plants, appreciate the value of the most perfect series of them in a fossil state.

Turning from this discouraging view of fossil botany in general to that of the particular formation to whose consideration the remainder of these pages will be devoted, it is satisfactory to find that it presents facilities for the investigation of its vegetable remains such as is afforded by no other. This is mainly due to the vast accumulation of specimens, and to many of them being presented under very different conditions in the under-clay, in the shales, in nodules of ironstone, and in the sand-

stone. Had it not been for these favourable circumstances, the study of coal fossils would have been apparently hopeless; for, whilst the clays and ironstone and sandstone scarcely ever contain more than one large class (ferns) in a fit state for determination, the shales preserve only the outlines of another (*Sigillariæ* and *Lepidodendrons*), whose affinities could hardly be guessed without a microscopical examination of their internal tissues, as these are preserved in the ironstones and sandstones. Considering of how exceedingly lax and compressible a tissue the coal-plants were composed, it is not wonderful that instructive specimens are rare; but to appreciate to its full extent how universal is the compression and how complete the mutilation of almost every individual, it is necessary to study the whole bed or deposit, *in situ*. Thus will be seen a layer of mineralized organic matter, exceeding in bulk and in area whatever any other formation may present in equal purity; for throughout the whole mass of the coal there will not be found one pebble or even grain of sand: it is a deposit of vegetable matter, so homogeneous that not a trace remains of the outward form of that incalculable number of species and specimens of plants to whose decay it owes its existence.

Plants, whose tissues are so lax as to be convertible after death into a mass of such uniform structure as coal, evidently would not retain their characters well during fossilization, under whatever favourable circumstances that operation may be conducted. We consequently find that few specimens are available for scientific purposes. Of the ferns, whose remains preponderate in the carboniferous Flora, only one surface of the leaves or fronds, and that invariably the least important (botanically speaking), is exposed to view; and their mutilation is so great that the identification of contiguous specimens is frequently impossible, much more so of those from different parts of the same or from other coal-fields. Were the species and genera identical with those now in existence, this difficulty would be lessened, for we should then know the variations in form which the individuals might be likely to assume, or, at any rate, what dissimilarity between the isolated fragments was due to their belonging to different parts of the same plant. The naturalist is thus hampered in the outset by his inability to answer questions relating to systematic and specific botany. And when he turns to a general review of the whole, and seeks to reclothe the globe with the vegetation to whose decomposition we are indebted for coal, he labours under no lighter difficulties: the most casual inspection of such a wreck suffices to show that the number of species, genera, and even orders, of which scarce a trace remains, must far outnumber those which are recognizable. Of the latter, again, but a small percentage is known in a tolerably complete state, only the larger and

better preserved specimens retaining those organs and appendages which the most skilful botanist requires to examine in the living vegetable before he can pronounce decidedly on its affinities. The female flowers or fruit are distinguishable in very few cases, and they are so rare that but one genus of coal-plants has thereby been referred with any certainty to its proper position in the natural system. They occur in the form of cones (aggregations of seed-vessels) or of isolated seed-vessels. Their form alone is generally preserved, their interior having been wholly destroyed, or presenting a crushed and shapeless mass of disorganized tissue. The solitary nuts, again, may have grown in cones or separately: they have never been found attached nor in a position relatively to any leaf, branch, or cone, that would justify their having belonged with certainty to either. Of male flowers no traces remain. Leaves and scales occur abundantly, but almost invariably detached, as is generally the bark of the stems or trunks, so that the very outline of the vegetable is frequently lost. Hence arises the necessity, in the infancy of this science, of describing the different portions, perhaps of one plant, as species, and of arranging them provisionally into genera; the word genus signifying, not a natural group of species, but a set of organs; and being synonymous in many cases with a shorter and more expressive Latin word, long in use and better understood. As an example, the genera *Strobilites* and *Lepidostrobus* may be cited, whose species are various cones (*strobili*), in some cases of *Lepidodendron*, in others possibly of other plants, widely different; even the order to which they belong being distinct from that including *Lepidodendron*.

This arrangement of portions of specimens under various genera is highly detrimental to the progress of systematic botany, but is not equally disadvantageous to the geologist, whose object it is to determine the relationship of strata, by means of a comparison of their contained species, without so particular a reference to their affinities. The identification of these is always open to question, from the errors into which the imperfection of the specimens necessarily leads. Two specimens of one plant, the one more perfect than the other, are frequently described as different: this is eminently the case in the *Sigillariæ*, the markings upon the surface of whose bark differ from those on the similar surface exposed by the removal of that bark, while in many specimens it is exceedingly difficult to determine whether the latter be present or not. The markings also vary extremely in different parts of the same trunk; insomuch that fragments which had been regarded as characteristic of six or eight separate species, have been more recently found to belong to one, that one presenting a surface equal to those six or eight fragments collectively, whereon the

supposed species were founded. Again, as the specific characters used in dividing this genus are drawn from what are considered very unimportant features in recent plants, namely the scars left by the fallen leaves, it is evident that several distinct species may be merged into one, in the absence of other distinctions beyond that solitary character which does not suffice to recognize analogously marked living vegetables.

The last obstacle which demands a passing allusion, because tending to retard our knowledge of coal fossils, is, that they cannot be investigated independently. Representing the earliest known Flora, the individuals composing it are, as might be expected, more unlike those now living, than what any subsequent formation contains. The succeeding beds present us with plants, which occupy, in point of organization, as in date of creation, a middle position; and it is in many cases through the investigation of these alone that a clue can be gained to the relationship existing between the earliest known and the now living vegetable forms. It is not so to an equal extent in the animal kingdom. A knowledge of recent shells, for instance, can be brought to bear upon those of the Silurian formation (independently of any study of their allies in the more modern strata) far more effectually than an equal acquaintance with living plants can, upon those preserved in our coal-fields. Many and sufficiently obvious are the reasons for this: the Silurian rocks contain but one or few orders of animals, the carboniferous many of plants. There is a greater external similarity between the shells of all periods—they are better preserved, and their external characters afford surer indications of their affinities, habits, and localities.

An examination of the coal vegetation being merely a comparison of its tribes of plants with those we are more familiar with, the first object of the naturalist is, to reduce all the strange individual forms he here for the first time sees, to the same classes and orders with existing ones. When their affinities cannot be traced, he seeks to ally them to living analogues, and thus, reproducing the whole Flora, he regards it as probably characteristic of such physical features of soil, surface, and climate, as accompany what he has determined to be the existing types of the by-gone Flora. The general laws now affecting vegetable life, are the only ones available in this comparison, and therefore are adopted as correct; but to appreciate the extent of their application, a very comprehensive knowledge of the distribution of plants is necessary. Slight local causes may very materially modify the operation of these laws; and so plastic is vegetation under their influence, that we find what appear to be entirely analogous positions with regard to heat, light, soil, and moisture, tenanted by whole genera, and even orders of plants, of very opposite botanical characters, and that

such localities present a greater disparity of vegetation than do other countries more remote in geographical position, and with less similarity in their conditions.

It is the case with very many species of existing plants, that they vary so considerably at various parts of the area over which they are dispersed, as to draw all but those who know the intermediate links (which may be comparatively scarce) into a belief, that the extreme varieties are specifically distinct. This is eminently true of ferns, which have very wide ranges, and are exceedingly sportive. If the difficulty be great with living plants, of which complete specimens or whole individuals are procurable, it must be far more so with fragmentary fossils; and the coal formation being characterized by ferns to a very remarkable degree, it follows, that with only imperfect specimens, all attempts towards determining the species and limiting them must be very vague. The amount of variation also is fluctuating, and it bears no necessary reference to botanical affinity; for whilst nine species of a genus may be constant to their characters wherever they occur, a tenth may vary so widely that its extremes will appear far more dissimilar than are any two of the other nine.

The knowledge of recent botany, which is needful to throw light upon the study of fossil plants and the origin of coal, must be both varied and extended; though a profound acquaintance with any particular branch is not required to make a very considerable progress. Those points with which the student should be most familiar are some of them purely botanical; whilst others are more general, and refer to the dependence of vegetation upon the condition of the area it covers.

Some acquaintance with systematic botany is the first requisite: through this alone can any approximation to the living affinities of the fossil be obtained. It should embrace not only a knowledge of the principal groups or natural order under which all plants are arranged, but a familiarity with vegetable anatomy; for when the stem or trunk alone is preserved, which is often the case, a minute examination of its tissues is the sole method of determining its position in the natural series.

A solution of the difficulties which this special knowledge will tend to remove is of the highest interest to botanists, though comparatively preliminary to the object of the geologist, whose inquiry is, what were the general features of such a vegetation as has effected the formation of a seam of coal, both as regards quantity and kind. As regards quantity, inasmuch as the growth was either wonderfully rapid, or more tardy, but prolonged under uniform conditions; and as regards kind, from certain species, genera, or orders, being particularly adapted by their quick growth, their gregarious habits, and their continued appropri-

ation of certain areas to produce those vast accumulations, the explanation of whose origin is still an unsolved problem. Other questions, which a study of living plants alone can answer, refer to the sorts of plants best calculated to thrive in such a uniform soil as the underclay, upon which each bed of coal rests, and into which some of the vegetables have certainly been rooted. What form of surface is best fitted to retain so mobile a débris as the coal was previous to its compression and hardening; what degree of dryness would be most favourable to such an accumulation, consistently with an energetic growth of vegetation.

The above considerations pre-suppose some general ideas of the vegetations both of the tropics and cooler latitudes, of mountain-chains, table-lands, valleys, and æstuaries, more especially of countries characterized by equable or by excessive or extreme climates, as compared with continents, and of humid and desert districts; in short, of all the complex associations with, or dependence of botanical characters upon, surface, soil, and climate, which the globe presents.

The want of this kind of information amongst many naturalists, and the neglect of its application by others, have caused those utterly contradictory opinions which have been expressed regarding the origin of coal,* and unnecessarily complicated the subject. The botanist must not seek to force a plant into a natural order, the habits of whose existing species are incompatible with those conditions under which a more comprehensive view of the coal formation may assure him it must have vegetated; nor can the geologist put forward any theory which will explain the features of that formation, if it be grounded on views opposed to those few certain data, which a study of the botany of the period in question has afforded.

There is another branch of this investigation of equal importance to the geologist and botanist, namely, the identification and comparison of the species from different and sometimes remote coal-fields, or from the various strata of the same field. This is as difficult as any of the points which occupy the botanist; and all questions connected with the geographical distribution of the plants of that period being dependent on the results thus obtained, it is one which requires extreme caution in the working. The obvious tendency in the student is to regard as

* The looseness of the speculations hitherto advanced on the relationship of the coal flora to such physical conditions as climate, cannot be better illustrated than by the fact that the *Sigillariæ* (which have undoubtedly contributed largely to the formation of coal) are considered by some naturalists to be allied to the order *Euphorbiaceæ*, by others to *Cacti*, and by the majority to ferns. The necessary conclusion to which those who place them in the first two orders would lead us, is, that they were inhabitants of singularly arid and desert countries; whilst, if ferns, they are characteristic of diametrically opposite conditions, a moist soil and a humid atmosphere.

identical the similar fossils in the various strata exposed in one mine; and as different the plants from remote coal-fields. From recent observations, it appears that subsequent movements may have isolated portions of what once formed a continuous bed of coal, characterized by a uniform vegetation throughout, and that hence a slight dissimilarity between the plants of each portion may be attributable to a difference in the conditions to which it was exposed in each. On the other hand, it must be borne in mind, that at the present day a change in position is almost surely accompanied by a very considerable change in vegetation. The labour of identification too is not confined to the comparison of specimens, but includes the determination of their names when previously described. This is often all but impossible, from the nature of the specimens, and the difficulty of presenting them, in an available form, without plates. Hence it happens, that the labour of individual observers is overlooked. It is, perhaps, impossible to employ similar materials to better purpose than has the author of the "Flore Fossile" those upon which he laboured; and yet the difficulty of naming the species by that work is very great, and must be so; for the specimens to be compared are, like the originals, mere fragments, and the genera of *Ferns* adopted are far from being properly defined, though as judiciously as the materials would permit. On the contrary, many of these are not supported by the examination of living analogues; whilst others are unavoidably founded on isolated portions of plants, whose appearances whilst living and affinities are alike unknown, whether amongst their contemporaries by which the world was then inhabited, or those hitherto unrecognised allies that may now surround us.

The foregoing remarks admit of illustration, to a certain extent, by particular instances. This may be useful, because indicating to the student those errors into which he is most liable to fall. Since, however, he may not be aware how closely the course of investigation pursued in the examination of a living Flora ought to be followed in studying a fossil one, it is, perhaps, well to enumerate those steps by which a knowledge of both can be obtained.

As a field for botanical research there is none so novel as the coal formation, the few yards of shaft being more than equivalent to the longest voyage, in respect of the amount and kind of difference between the vegetation the naturalist is acquainted with and that he seeks to understand. Whatever be the nature of the vegetation to which the botanist is transported, he commences by observing:—1. What are the orders, genera, and species of plants characterising the Flora; their mutual affinities, and their relations to those of other countries; their numbers, and the relative proportions which the natural groups under which they arrange themselves, bear to each other. 2. The geographical distribu-

tion of the species, &c.; their extension over the surface of the country, and the replacement of one kind by another. 3. The relations which may be traced between the species and the soil to which some are peculiar, whilst others are common to it, and to very different soils; the quantity of moisture, heat, and light they require, and the effects of a diminution or increase of any of these elements. 4. The reciprocal influence of the whole mass of the vegetation upon the surface it covers; the new soil, or alteration of the old, produced by its decay; the extent and composition of accumulations of dead matter; the particular kinds of plants contributing most largely to, and the consequent nature of, such deposits; the conservative influence of the vegetation upon this deposit, which may be retained by roots, and sheltered by foliage from the action of elements, which, in the absence of these protections, would rapidly sweep it away.

An enumeration of these points, viewed in their bearing on the subject of the Coal-flora, will show how limited is our knowledge of any one of them, compared with what might be acquired from a very superficial examination of any recent flora, or with what the geologist may obtain from an inspection of the animal remains in many strata.

1. Of the mutual affinities of the groups under which the majority of the genera of coal-plants arrange themselves, little more can be said, than that the *Ferns* occupy the lower end of the series, and the *Coniferæ* possibly the highest; but this depends upon the view taken of the affinities of *Sigillariæ*, the most important group. These are classed by some observers amongst *Ferns;* by others, with *Coniferæ;* another considers them as linking these two widely-different families; whilst a fourth ranks them much higher than either. The affinities of another group, *Calamites*, are entirely unascertained. Of the whole amount of species in each, no conjecture can be formed; or any but a very rough one of the number into which those with which we are familiar, as of common occurrence, should be divided. The ferns far out-number, probably, all the others; but this again materially depends on the value accorded to the markings of *Sigillariæ*, as means of dividing that genus; for if the slight differences hitherto employed be insisted upon, the number of the so-called species may be unlimitedly increased.

2. With regard to the geographical distribution of the species, &c., it appears that an uniformity once existed in the vegetation throughout the extra-tropical countries of the northern hemisphere, to which there is now no parallel; and this was so, whether we consider the coal plants as representing all the flora of the period, or a part only, consisting of some widely-distributed forms that characterized certain local conditions. Nor is this uniformity less conspicuous in what may be called the vertical distribution, the fossils in the lowest coal-beds of one field,

very frequently pervading all the succeeding beds, though so many as thirty may be interposed between the highest and the lowest.

3. Of the relations between the soil and the plants nourished by it, little more is recognizable, than that the *Sigillariæ* have been particularly abundant on the under-clay, which, judging from the absence of any other fossils but *Sigillariæ* roots (*Stigmaria*), seems to have been either, in itself, unfriendly to vegetation, or so placed (perhaps from being submerged) as to be incapable of supporting any other. The latter is the most probable, because both *Sigillariæ* and their *Stigmaria* roots occur in other soils besides under-clay, and are there accompanied by *Calamites*, *Ferns*, *&c.* The *Coniferæ*, again, are chiefly found in the sandstones; and their remains being exceedingly rare in the clays, shales, or ironstones, it may be concluded that they never were associated with the *Sigillariæ* and other plants which abound in the coal seams; but that they flourished in the neighbourhood, and were at times transported to these localities. The quantity of moisture to which these plants were subjected must remain a question, so long as some authors insist upon the *Sigillariæ* being allied to plants now characteristic of deserts, and others, to such as are the inhabitants of moist and insular climates. The singularly succulent texture and extraordinary size of both the vascular and cellular tissue of many, possibly indicate a great amount of humidity. The question of light and heat involves a yet more important consideration, some of the coal-plants of the Arctic regions being considered identical with those of Britain. How these can have existed in that latitude, under the now-prevailing distribution of light and heat, has not been hitherto explained: they are too bulky for comparison with any vegetables inhabiting those regions at the present time, and of too lax a tissue to admit of a prolonged withdrawal of the stimulus of light, or of their being subjected to continued frosts.

4. The consequence of the existence of the coal-plants has been the formation of coal; but how this operation was conducted is a question still unsolved. The under-clay, or soil upon which the coal rests, and upon which some of the plants grew, seems in general to have suffered little change thereby, further than what was effected by the intrusion of a vast number of roots throughout its mass. The shales, on the other hand, are composed of inorganic matter, materially altered by the presence of the vegetable matter which they contain. The iron-clays again present a third modification of this mixture of organic and inorganic matter, often occurring in the form of nodules. These nodules seem to be the result of a peculiar action of vegetable matter upon water charged with soil and a salt of iron, the iron-stone nodules of existing peat-bogs appearing altogether analogous to those of the carboniferous period, whether in form or in chemical constituents.

Here, then, the botanist recognizes in one coal-seam a vegetable detritus under three distinct phases, and which has been acted upon in each by very different causes. In the under-clay there are roots only:* these permeate its mass, as those of the water-lily and other aquatic plants do the silt at the bottom of still waters.

The coal is the detritus either of those plants whose roots are preserved in the under-clay, or of those, together with others which may have grown amongst them, or at a distance, and have been afterwards drifted to the same position.

Above the coal is the third soil, bearing evidence of the action of a vigorous vegetation; this is the shale, which has all the appearance of a quiet deposit from water charged with mineral matter, and into which broken pieces of plants have fallen. Here there is so clear a divisional line between the coal and shale, that it is still a disputed point whether the plants, contained in the latter, actually grew upon the former, or were drifted to that position in the fluid which deposited the mineral matter. Amongst the shales are also interspersed, in many cases, innumerable stumps of *Sigillariæ*, similar to those whose roots occur in the under-clay, and which are themselves found attached to those roots in soils similar to the under-clays, but unconnected with any seam of coal. These stumps are almost universally erect, are uniformly scattered over the seams, and otherwise appear to have decidedly grown on the surface of the coal: the shales likewise seem deposited between these stumps. The rarity of *Sigillariæ* roots (*Stigmariæ*) in this position, is probably due to their being incorporated with the coal itself, though they sometimes occur above that mineral and between the layers of shale. The seams of iron-stone (or black-band) are the last modifications of soil by vegetable matter, to which allusion has been made: when these are uniform beds or layers, they may be supposed to be the deposit from water charged with iron and soil which has percolated through the peat, and in so doing absorbed a great deal of vegetable matter. The layers of nodular iron-stone are simple modifications of these, and may be caused by the sedimentary particles contained in the fluid, which, instead of being deposited in a uniform stratum, are aggre-

* The absence of other parts of plants, and indeed of any plant but the roots of *Sigillariæ*, in the under-clay, appears a fact of considerable importance. In the first place, it indicates that that soil was in a condition unsuited to the growth of other vegetables (as mentioned above), whose seeds might have accompanied those of that genus on its previously-naked surface. In the second place, this absence of other fossils in the under-clay is opposed to the theory of the drift-origin of the vegetable matter comprising coal; for there is no interstratification of coal with this subjacent deposit, which might have been expected to occur over some portion of an extensive coal-field; whereas, the gradual decay of these plants, whose roots struck into the under-clay, would produce a uniform bed of peat, perhaps adapted to the growth of those ferns and other plants which are fossilized in the superincumbent shales.

gated round broken bits of vegetable matter (as fern leaves, stems or cones) which served as nuclei.

Now, though each of these points admits of some explanation when taken independently, and some illustration from the action of an existing vegetation upon soil, &c., it is very difficult to understand their combined operation over so enormous a surface, for instance, as one of the American coal-fields, and even more to account for their regular recurrence, according to some fixed law, in every successive coal-seam throughout the whole carboniferous formation. These are problems of the highest order and unsuited to this sketch, the remainder of which shall refer to the plants themselves, and especially to those botanical characters according to which the Coal Flora has been grouped and named, and to an illustration of these several points by a comparison of them with what are afforded by recent plants.

ON THE PROBABLE EXTENT OF THE FLORA OF THE COAL FORMATION IN BRITAIN.

No fewer than 300 species of plants have been enumerated as belonging to the Coal Flora of Great Britain; but whether this gives any approximation either to what was the amount of their species at one period, or even to all those which contribute to form the coal, it is impossible to say. It need hardly be observed, that a collection of the fragments imbedded in our most recent deposits is no index to the general mass of the vegetation, nor are the remains necessarily those of the commonest plants, or even of such as would *à priori* be judged the best suited for becoming fossilized. That hitherto unknown species do exist in an available state for the botanist cannot be doubted: they are of frequent occurrence; but that these are not so numerous as might be expected from the enormous magnitude of a coal-field, is evident, from the great uniformity that prevails throughout the formation. It may indeed be a query, whether the number of species still to be discovered will equal in amount that of the so-called species, which being founded on imperfect specimens, will ultimately prove to belong to previously described forms.

That the vegetation of the carboniferous period, whether confined to the coal veins or not, was highly luxuriant, cannot be disputed. The enormous bulk of carbon accumulated, and the prevalence of ferns in all the fields, and the great size to which so many soft-tissued plants attained, all prove this fact. A luxuriant vegetation is, however, no index to a varied one; and, as many of our modern woods and even great areæ of tropical forests consist of but a few species multiplied *ad infinitum*, so may the forests of the carboniferous period have been composed of but a few *Sigillariæ* and *Lepidodendrons*, sheltering an under-

growth of a limited number of kinds of fern,* for a very limited number of them (comparatively speaking) if as protean as some of their allies are in our day, would embrace all the known species of the Fossil Flora.

In the temperate latitudes particularly, a recent Flora, marked by a preponderance of ferns, is almost universally deficient in species of other orders; as is thus shown. 1. Where one species prevails over a considerable area, as the bracken (*Pteris aquilina*) does in parts of Britain, and the *P. esculenta* in Van Diemen's Land and New Zealand, it generally monopolizes the soil, choking plants of a larger growth on the one hand, and admitting no under-growth of smaller species on the other. 2. A luxuriant vegetation of many species of ferns, continued through a great many degrees of latitude or longitude, especially in the temperate regions of the globe, generally indicates a uniformity of temperature throughout that area, and a paucity of species of flowering plants. A comparison of the vegetations of Tasmania and New Zealand illustrates this. The former of these islands, barely 200 miles long, contains four times as many species of flowering-plants as New Zealand, whose total length is 900 miles. On the other hand, this latter country possesses more than four times as many kinds of fern as Tasmania, and they are so uniformly distributed over its area, that almost all those which are found at the southern extremity of the island prevail also at the northern. The West Indian and Pacific Islands again present a Flora remarkably rich in ferns, and in both these instances we have very many of the species uniformly spread over an enormous surface, in the one instance, from the Windward Islands to Mexico, and in the other from New Zealand to the Society and Sandwich Islands. Take on the other hand the campos of Brazil, the sandy flats of Southern Africa, and the somewhat similar plains of Australia, and sterile though they appear at first sight, they will be found to abound in many kinds of flowering plants, but unaccompanied with ferns.

This prevalence of ferns has been long adduced in proof of the climate of the carboniferous period being temperate, equable and humid; and so it no doubt was; but I am not aware that it has been hitherto regarded as probable evidence of the paucity of other plants, and the general poverty of the whole Flora which characterized that formation. If, however, the laws of existing vegetation are to be considered as having had equal force at that time when the fossil one

* This preponderance of ferns over flowering plants is common to many tropical islands, and not confined to the smaller of them, as St. Helena and the Society group. In extra-tropical islands, too, as New Zealand, I have collected as many as 36 kinds of fern in an area not exceeding a few acres: they gave a most luxuriant aspect to the vegetation, which presented scarcely a dozen flowering plants and trees besides. An equal area in the neighbourhood of Sydney (in about the same latitude) would have yielded upwards of 100 flowering plants and but two or three ferns.

flourished, we must conclude that the predominance of ferns in general, and of certain species of *Pecopteris* (a fern apparently allied to our *Pteris*) over a great area, together with the remarkable similarity of the English fossils with those of North America, are all indications that the Flora of that period was poor in number of species.

Let it not be supposed that this prevalence of an order, which in point of complexity of structure is low in the system of plants, is a fact favourable to the hypothesis that the vegetation of which it appears to form a large part, was less highly developed than what succeeded it. We know too little of the structure of the ferns of that day, to pronounce them either more or less complete than their allies of the present time; while of the *Lycopodiaceæ** it may be safely asserted, that they were of a form and stature far more noble, and in structure more complicated than any plants of that order now existing.

ON THE MOST PREVALENT GENERA OF PLANTS BELONGING TO THE COAL FORMATION, AND THE CHARACTERS EMPLOYED IN THEIR CLASSIFICATION, AND THAT OF THE SPECIES THEY CONTAIN.

§ *Ferns, General Remarks.*

Numerous as are the dissimilar groups of plants (whether genera or orders) scattered through the various strata of the coal formation,

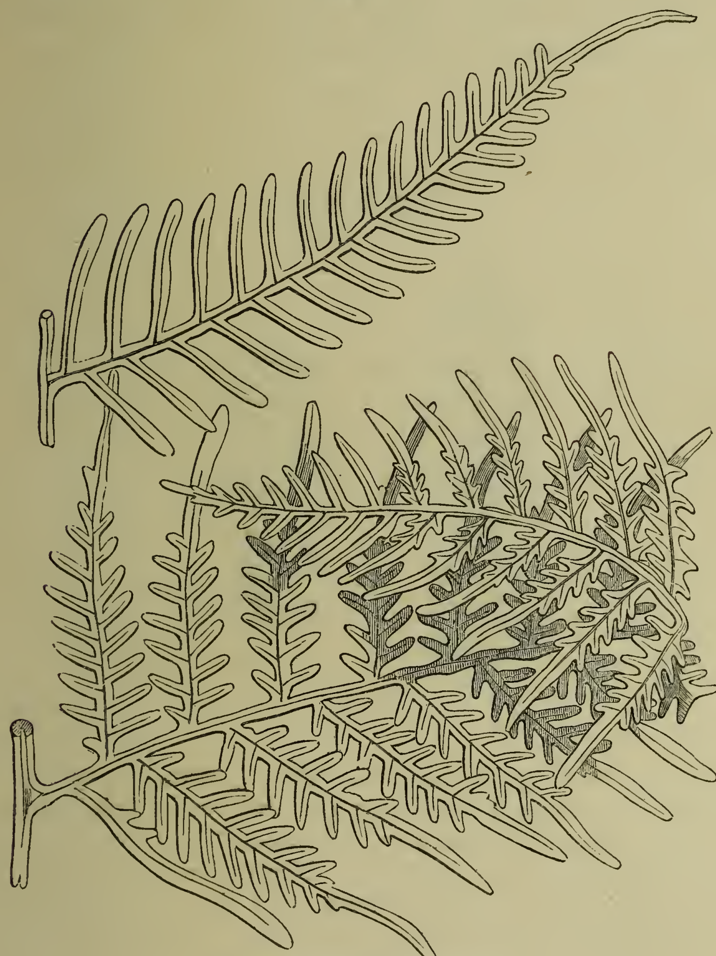
Fig. 1.

Pecopteris heterophylla (Coal-fields, Newcastle).

* See "Essay on the Structure and Affinities of *Lepidostrobus*," in the present volume of Survey Reports.

there is but one which presents any obvious or recognizable close relationship with an order now in existence. Such is that of the ferns. These were not only undoubted ferns, such as we have now living, but one of the many fossil genera included under this order is probably identical with a living one, though none of the species comprised in it are alive now. The genus here alluded to is *Pecopteris* (Fig. 1), the fossil representative, if not congener, of the modern *Pteris* (Fig. 2).

Fig. 2.

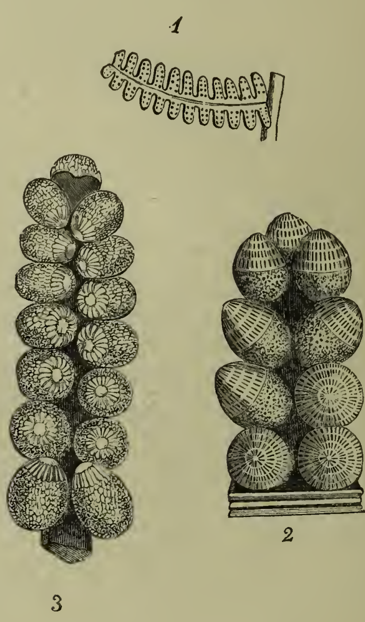


Pteris esculenta (New Zealand).

It is not improbable that there are other genera of living ferns fossilized in the shales of the coal formation, but if so they are not so well preserved, probably from not offering the facilities for petrifaction (in a determinable condition) that *Pecopteris* does. The perfect state in

which this genus is often found is attributable partly to its characteristic fructification being copiously produced, to its fronds being of a hard texture and coriaceous consistence, and to the absence of hairs or glands upon the under surface where the spores are produced, and to the large size, smoothness, and evenness of the involucre, or organ protecting these spores. A few other ferns of this formation present the fructification well preserved, and especially the genus *Senftenbergia* of Corda* (Fig. 3, 1 & 2), which is allied to the recent *Aneimidictyon* (Fig. 3, 3); but in no case except *Pecopteris* can the genus be thereby, even provisionally, identified with any living one.

Fig. 3.



The ferns are a group of plants, whose genera and species vary extremely in the form of their fronds, and are sometimes so bizarre that without the organs of fructification it is impossible to ascertain even on the order they sometimes belong to. Now the fruit is so universally present and abundant in recent ferns, that there is no difficulty in defining the limits of the order as it now exists; but in the case of fossil ferns, in most species of which the fruit is of rare occurrence, and partially obliterated by fossilization, it is impossible to decide whether

* Corda "*Flora der Vorwelt*," Tab. 57, fig. 2. I have introduced a copy of Corda's figure of the remarkable fructification of this plant; as from the scarceness and high price of that work it must be inaccessible to most of our readers.

many of the genera put into the order (as *Asterophyllites,** *Sphenophyllum*, &c.) really belong to it or not, until some evidences be gained from their fructification.

This absence of fructification not only prevents our defining the limits of the fossil ferns as an order, but deprives the botanist of one of the most important generic characters that the plants comprised in it afford. As will be hereafter shown, it is generally impossible to trace the affinities of a fern without the fruit, and often even to refer it to the section or subdivision in which it should be placed.

There are two other points which cannot fail to strike the observer of fossil ferns: they are, the absence of a singular aspect of fronds in a state of incipient vernation, that is curled up like a crozier, as the fronds of all are in a young state. In the perennial existing species, fronds in this state may be seen on the plants at all seasons, and even in the annuals they are visible for many months; so that it were difficult to select a season of the year during which a modern fern Flora could be fossilized without very many such fronds being preserved, as well as fully expanded ones; but in the coal formation these are excessively rare. That they do occur is evidence that the evolution of the leaves followed the same law then as now; while this extreme infrequency would seem to indicate, either that the majority of the species were annual, and fossilized at an advanced season of the year, possibly coinciding with a sudden depression of the surface; or that they were perennial, and the old fronds dropping from time to time off the parent trunk, were subsequently fossilized.

Again, the almost universal absence of any defined termination to the stalks (stipites) of the fronds, or of any such masses of woody roots or rhizomata as those of modern ferns, is highly remarkable.† In the case of recent species we find long and strong under-ground woody roots, or more frequently great knotty masses above the surface of the earth, from out of which the fronds spring. But in the case of fossil ferns, there is hardly such a thing known as a specimen presenting two fronds attached to one stem. This may readily be explained on the supposition that the ferns are all fragments, transported to the position they now occupy, an hypothesis gravely objected to by many close observers on geological grounds. Another suggestion which offers itself is that the fronds are the deciduous ones of tree-ferns; this is much more plausible, though almost necessarily involving the con-

* My friend, Mr. Bunbury, informs me that he is possessed of American specimens of this genus with the organs of fructification preserved.

† Several authors have figured small ferns, in which both the fronds, their axis of support, and root, are well preserved; but the species are very scarce, much smaller, and of a different character to the prevailing forms of the coal formation.

clusion that *Sigillariæ* are the trunks of those tree-ferns, a subject to which I shall revert at a future part of this essay. A third and the only other explanation that I can propose is, that the roots were planted in the peat, and with that are now turned to coal, thus being as effectually obliterated as are the roots of those numerous upright stumps of *Sigillariæ* which I consider to have undoubtedly grown on the surface of the coal, and spread their roots into, or along the surface of its mass.

No fewer than one hundred and forty species of ferns are enumerated as having inhabited those few isolated areæ in England over which the coal has been worked, at the time when the latter was formed. This is a strange contrast to our existing Flora, which boasts but 50 species of that order, upon a surface of incomparably greater extent than what we have examined of the carboniferous period. It is, indeed, doubtful whether all the fronds now in Great Britain would equal in number those contained in the largest seams; so that under whatever light the predominance of the ferns be regarded, whether in amount of species or specimens, they indicate a climate far different from the present. I have before said, that it is only in the tropics, and in the equable, moist, higher latitudes of the southern hemisphere, that any remarkable luxuriance of ferns is met with. A climate warmer than ours now is would probably be indicated by the presence of an increased number of flowering plants, which would doubtless have been fossilized with the ferns; whilst a lower temperature, equal to the mean of the seasons now prevailing, would assimilate our climate to that of such cooler countries as are characterized by a disproportionate amount of ferns. This then is an argument unfavourable to the theory of central heat having warmed the surface, or of the direction of the poles being so altered as to have exposed Great Britain to a tropical climate, and demanding only a different disposition, and perhaps proportion of land and water to that now existing; judging from the southern hemisphere, where it is seen that the relative proportions of land and water modify the Flora most materially.

With regard to the distribution of these fossil ferns out of Britain, it appears that their ranges were as wide as are those of the present day; perhaps more so, when we consider how extremely difficult is the determination, and no less the identification of the species and specimens, and that the general tendency is probably to the multiplication of species. Of the British species, about 50 are known to occur in the coal-beds of North America, some of them ranging there from the latitude of Nova Scotia to 35° S., and abounding in these and various other intermediate coal-fields. On the continent of Europe again there are about as many of the British species.

Again, turning to the living ferns, we find that of the 50 inhabiting

Great Britain, little more than a half are found in North America. A greater similarity between the climates of these countries is required to account for the preponderance of the species common to both during the carboniferous epoch, and possibly the presence of land between the two to have favoured the transmission of seeds from one to another. That such an aid as an intermediate land was necessary, however, may be disputed, on the ground that the *Lycopodia* of Europe are all found in North America, their spores being apparently no smaller nor easier wafted than are those of the ferns.

Nothing satisfactory has been elicited regarding the vertical distribution of the species, beyond the fact that no decided difference between those of the uppermost and lowermost beds has been hitherto ascertained. A few of the species are found in the Old Red Sandstone, but none enter the superior beds, as the Oolite, &c.

Ferns—Botanical Remarks, &c.

Habit.—Upon this point we absolutely know nothing. Although the fronds occur in countless myriads throughout all the beds, they offer no characters, either relative or individual, by which we can pronounce whether they were terrestrial or epiphytal (growing on trunks of trees), if the stems were erect, inclined, or creeping; nor, what is most remarkable of all, do the fronds ever occur attached; so that we are ignorant whether any or all of these kinds belonged to tree-ferns, or were humble individuals, with stems scarcely rising above the ground.

This ignorance of the habit of the plants is a most serious drawback, and till it is removed we have little hope of gaining a clear idea of the features of that vegetation to which they so largely contributed. It may be urged in favour of a great proportion being arborescent, that none are found attached, as stated above, to roots or slender stems; and that some may have belonged to *Sigillariæ*, with whose foliage we are otherwise unacquainted. Against this supposition, again, stands the extreme rarity of any acknowledged tree-fern stems in the coal-beds, and that whether drifted or deposited on the spot, the fronds must, if arborescent, have been accompanied by such stems.

The infrequency of fructification upon the fronds of the fossil ferns belonging to this formation appears as possibly another argument in favour of many of those appertaining to tree-ferns; for, while the herbaceous and caulescent ferns of New Zealand are scarcely ever barren, the arborescent species are almost invariably so. I think I am safe in saying that of two or three kinds of New Zealand tree-fern, not one specimen in a thousand bears a single fertile frond, though all abound in barren ones.

Fructification.—The sporules (fruit or seeds) of the ferns are invariably produced on the under-side of the frond, and as that is all but universally the concave surface, and generally presents other inequalities beyond those caused by the organs of reproduction, it becomes firmly attached to the rock during petrifaction, and very rarely exposed to view. Hence, when the frond is coriaceous, it cannot even be determined whether the plant was in fruit or not, except in such rare case as that of *Pecopteris lonchitica*, to which I have already alluded. When, however, the texture of the frond is membranous, the position of the sori (or clusters of spores) is indicated by a prominence on the upper and exposed surface. This stamping through is usually the only apparent sign of fertility in fossil ferns, and is conspicuous in several British species (as *Pecopteris obtusifolia*); also in three American species, indicated by Mr. Bunbury,* who has lately drawn attention to the circumstance. Lindley and Hutton were, I believe, the first to point this out as the probable cause why the fructification of fossil ferns should be very seldom apparent, even supposing fruiting specimens more frequent than they really are.† Goeppert ‡ again finds that in producing artificially fossilized ferns, the under surface invariably remains attached to the matrix, which separates from the upper.

It is, unfortunately, impracticable to class the most perfect specimens of living ferns without the aid of characters derived from their sori. Much more is this the case with the imperfect ones of the fossil. The former indeed are almost universally rejected from the Herbarium, many species being in every other respect identical.

In illustration of this fact two wood-cuts have been prepared, each displaying how great a difference may occur in fructification unaccompanied by any disparity in the outline, form, surface, texture, or venation of the frond.

The first (Fig. 4) represents a portion of a frond whose outline and venation answer either for a species of *Leptogramma* (A) or of *Asplenium* (B), genera which are precisely alike in those points ; but if the fructification be regarded, it will be seen, that the sori of the portion, marked (B) and enclosed in the black line, are covered with a protecting scale (involucre or indusium) as is more distinctly shown in the magnified portion, whilst those of the rest of the figure are naked. Now this absence of an involucre in *Leptogramma* is not accidental in that fern, but a constant character, separating both it and many allied species (all equally wanting the involucre) from *Asplenium*, and a similar group which possess that organ.

* Fossil Flora sub *Neuropteris undulata*, t. 83.

† "Quarterly Journal of London Geolog. Soc.," vol. ii. p. 85.

‡ "Systema Filicum Fossilium," p. 293.

At Fig. 5 again a portion of a fern frond is figured, which, when out of fruit, would be referred indiscriminately to one of four species, differing only in the form, protection, or position of their sori. Thus, at

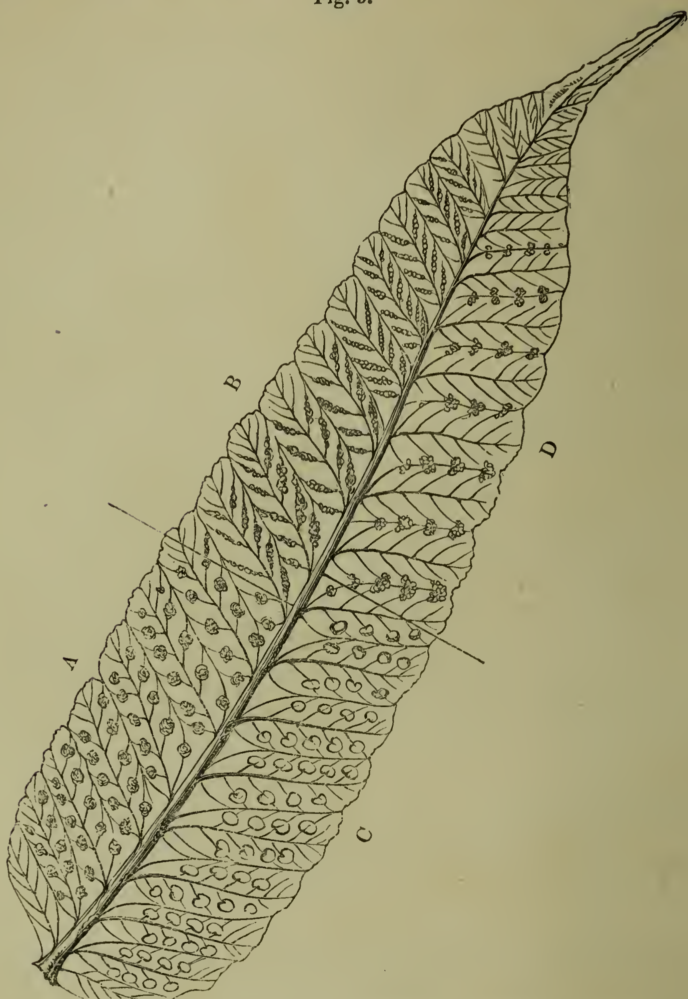
Fig. 4.

Fig. A, the sori are placed on the middle of a venule, and are unprovided with an involucre: were the whole frond thus characterized it would be that of *Goniopteris crenata*. At B the sori are elongated, covering the whole venule; it is *Stenogramma aspidioides*. Fig. C shows the sori to be situated at the middle of a vein (as in A), but they are here covered with an involucre, and not exposed; such is the case with *Nephrodium glandulosum*. The sori at D again are naked and round (as at A), but instead of being placed in the middle of a

venule, they occur only where two venules meet: were the whole frond so furnished it would represent *Meniscium cuspidatum.**

Thus we have four plants, wholly indistinguishable except by their

Fig. 5.



* To illustrate still further the confusion which the absence of fructification might entail, it may be mentioned that three of these ferns are natives of Java, and would, if petrified without the fructification being displayed, be unsuspectingly referred to one species; the fourth, a native of Jamaica, would, if similarly fossilized, be adduced as an instance of the similarity in the vegetable productions of the Old and New World at the epoch when they both flourished! Yet four more really and truly distinct plants cannot well be.

fructification, which proves them to belong to different groups of the order. It has been already remarked that the fruit is rarely present in fossil ferns; whence it may be presumed, that did the four ferns just described occur fossil, the probability is great that whatever formation they inhabited, or however widely separated they were in geographical position, they still would all be included under one species.

Fig. 6.

Again, very many existing species of ferns have the fertile frond quite distinct from the barren ones in size and shape. The *Niphobolus rupestris* of New Zealand is an instance: a wood-cut of it (Fig. 6) is added. In such a case the absence of any fructification on the one hand, and the severance of both the fertile and barren fronds from the

caudex previous to fossilization, would effectually prevent the two parts being recognised as portions of one plant.

The tendency in this case is towards the multiplication of species, while in the former we should unite what are nearly totally distinct.

Venation. In the absence of those characters afforded by fructification which are acknowledged to be of the very highest value in this order, if indeed they are not the only ones by a study of which the primary groups of ferns are to be united, the venation, or arrangement of the nerves, is adopted. This character is considered by many of secondary importance, and one by which the primary groups may be divided into minor groups without violence to nature, especially according to whether the veins after branching join again, or continue free to the margin of the frond. Now, there are doubtless many sub-orders both of fossils and recent ferns distinguished by the organs of fructification, each of which again is sub-divided by characters in the venation; but instead of adopting the primary characters (of fructification) in the formation of these sub-orders, the secondary ones (of venation) are employed: it follows, then, that every such group (and they are genera) of fossil ferns may contain species generically widely apart. The genera must, of course, be wholly artificial, and include plants belonging to separate sub-orders, as would be proved did their fructification occur.

Even venation is a character to be used with caution; for though the presence or absence of an involucre to the sorus is constant in one species, and so are the form and position of the sori, the venation is found occasionally to vary materially in different parts of the same plant, or even the same frond. Hence, while some sub-orders of ferns may be trenchantly divided according to the branching of the nerves, others cannot, because the individual species at times assume both forms in one frond.

This is remarkably the case with the *Diplazium Malabaricum*,* of whose fronds two states are figured (Fig. 7). In the upper and older portions it will be seen that the veins, after branching, meet; while in the lower the branches run free to the margin of the frond. Fossil fragments of this fern would be included under two genera, those as resembling Fig. A to *Callipteris*, and those veined in B to *Digrammaria*. It would be out of place to exhibit through what transition stages the passage between A and B is effected: any one frond, however, of this par-

* This plant has caused no little perplexity to the students of existing ferns. So protean are its fronds, that different states of this one fern have been made into two separate genera, *Anisogramma*, Pres., and *Digrammaria*, Presl. Mr. John Smith, of Kew, to whom I owe many illustrative specimens of these points, has separated this plant from *Diplazium*, and given it the name of *Callipteris*.

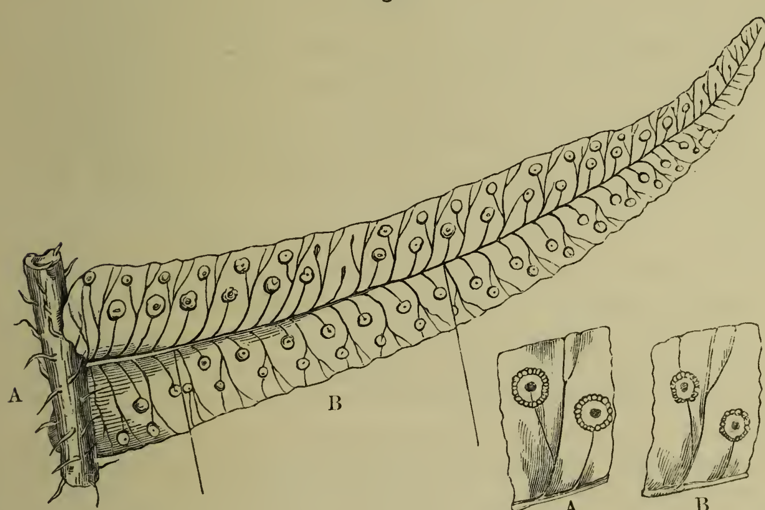
ticular species shows it, and would afford material, if fossilized, for many bad species.

Generally speaking, however, venation is a character of the greatest

Fig. 7.

importance; and to show how closely it should be scrutinized, an illustration is added (Fig. 8) of a form of frond and fructification common to two very different ferns, which are permanently and effectually distinguishable by the length of one branch of a repeatedly branched vein.

Fig. 8.



The general character of the frond of both A and B is to have the veins alternately simple and branched, the simple one is in both produced only half-way towards the margin, and bears a sorus on its point,

the longer is in both three times branched, and bears a sorus on the first or right-hand branch. But whereas in A (*Cyclopeltis Presliana*, Sm.) the said first right-hand branch or venule is not produced to the margin of the frond, and bears its sorus on the point, in B (*Cycl. semicordata*, Sm.) the same venule is produced to the margin, and has the sorus on its middle. Now this arises from no difference of specimens, but of species, and it is the only character by which a plant exclusively inhabiting the Old World can be distinguished from one confined to the New.

Though such an anomaly as that of a *growing* fern bearing fronds with two different types of venation is readily recognized amongst recent plants whose whole frond is presented to the eye, it is not so in the petrified specimen, of which isolated fragments must be classed under different genera according to the arrangement of the veins. This is probably a fertile agent in dismembering genera, an error no less grave than that to which so slight a character as that distinguishing *Cyclopeltis Presliana* from *C. semicordata*, would, if overlooked, lead; for hence we might specifically unite the widely different ferns of two more differently circumstanced countries than Europe and North America.

Lastly, many recent ferns are of so dense and leathery a texture that their venation cannot be ascertained without much trouble, arising from the necessity of macerating the frond and dissecting out the veins. When such are petrified, they cannot be referred with propriety to any previously established genus, the characters afforded by texture, and comparative denseness of substance, being of specific importance only.

The conclusion to be drawn from the above resumé of the value of the characters drawn from the venation of fossil ferns is that the prevailing tendency of dwelling too much upon it leads to the dismemberment of species, and placing the individual parts under different genera.

Outline and Division of Fronds.—A character considered next in importance to venation, both amongst recent and fossil ferns. It is seldom of more than sectional or specific value, and frequently not that, the species of a genus being frequently grouped into those with simple fronds, those with the fronds lobed, deeply divided, once, twice, and so forth.

In some cases of living ferns even the amount of variation is very startling, for instance the *Polypodium pustulatum* (Fig. 9), where the fronds are sometimes entire, at others deeply lobed; or still more remarkably in the case of *Lindsæa cordata* (Fig. 10, p. 414), whose fronds vary so extraordinarily, that did the various forms occur petrified, and detached from the parent plant, it would be impossible to deny specific

value to some dozen, or more, of such isolated fragments as would alone be found. Further instances of variation of form in the same plant are given at Figs. 1 and 6 of the illustrative wood-cuts.

Fig. 9.

On the whole, it is probable that the irregularity of outline and division, prevalent in recent ferns, is the most fertile source of error in our investigations amongst the fossil, because the individual fronds are universally detached, and are seldom seen entire, so that we are ignorant to what portion of the plant the fragments belong. The result is of course the multiplication of species to a degree only commensurate with the protean nature of the species.

The zoologist is not equally hampered with the three classes of difficulties described above. Take the mollusca for instance; there is hardly an instance of two shells, identical in appearance, yet belonging to different genera of that order, and only distinguishable by the animal they contain, or by one organ of that animal; far less of four genera of shells so circumstanced, and each the type, not of a genus, but of groups—groups, too, differing in geographical distribution as well as in their most important characters.

Fig. 10.

Outline again, a fallacious guide to the determination especially of generic affinity amongst plants, is of eminent importance in the animal kingdom, where the habits of the different groups, all locomotive, demand peculiar modifications of the hard parts, whether of the external or internal skeleton.

Surface.—The presence or absence of hairs or scales on the surface of the fronds, and sometimes of glands also, affords characters of the greatest constancy for distinguishing species, being often available when the outline of the fern is so variable, that by it alone the species cannot be traced. The larger and most characteristic hairs or scales occur

chiefly at the base of the frond-stem or stipes, a part of the plant invariably wanting in the fossil. Smaller scales, hairs, and glands are most frequently confined to the under surface of the frond, which, from various causes, and this amongst others, is almost invariably the one that is united to the rock in petrified ferns, and therefore unavailable for botanical examination.

Sigillaria.

Perhaps the most important plant in the coal formation, forming a conspicuous feature in almost every field, appearing in all the strata, and distributed from Spain to Scotland and from Virginia to Newfoundland in America. Upwards of 60 species have been described; with how little precision may be inferred from the fact mentioned above, that many of them have been proved mere varieties, in a solitary case even four being reduceable to one.* Under the names of "bottoms" and "bell-moulds" the stumps of *Sigillaria* are well known to the colliers, as dangerous associates of the shale roofs in the workings, immediately above the coal. They are generally but a few feet high, though sometimes two yards broad at their expanded bases, they are truncated at the top, and retain their position in the shales after the removal of the coal upon which they rested, being supported by the pressure of the atmosphere and the cohesion of their smooth sides. Unless propped, they, after a time, lose their hold and fall in, sometimes severely injuring the workmen. So common are they, that I have in many South Wales and other collieries counted five or six in the space of a few fathoms, always suggesting the idea of the erect stumps of trees in a forest.

In the shales surrounding the bases of these stumps are found prostrate stems, bearing markings similar to what sometimes appear on the stumps. It is, however, generally the case that the markings of the stumps are very obscure or wholly obliterated, as usually occurs on the lower parts of the stems of those plants which at an earlier stage bear deciduous organs. This absence of marking has been urged in proof of these stumps not being *Sigillariæ* at all; but we know no other genus to which they can be referred; and in the noble erect specimens discovered and examined by Mr. Binney, the gradual evanescence of the scars or even flutings of the trunk at a few feet above the root, is very decidedly shown in most instances, though in some they may be traced almost to the base.

That the *Sigillariæ* were of a very brittle and probably lax tissue, is I think evident by the constantly truncated upper end of the stumps in the shales, their never being prostrated entire, and the singular com-

* Mr. Binney, of Manchester, showed me a *Sigillaria*, in which the characters of *S. catenulata, reniformis, organum,* and *alternans* were all displayed, a fact he has alluded to in the Manchester Philosophical Magazine for October, 1844.

pression of the prostrate portions. I am not aware that they have ever been found prolonged upwards from the roof of one coal-seam *through* another one, as the coniferous * fossil discovered by Mr. Binney was. This may be owing either to their generally lower stature, or more probably to their not being capable of surviving the geological changes which that harder-wooded plant did.

External Form of Sigillariæ.—It is highly singular that this fossil should be of such universal occurrence and yet be unaccompanied by any evident traces of branches, leaves, flowers, or fruit, and that till very recently the probability of its roots being *Stigmariæ* was called in question by most. Except, however, we assume that some *Lepidodendrons*, which almost universally accompany *Sigillariæ*, were the branches of that genus, or that the fern fronds deposited round their bases were their foliage, we cannot hazard a conjecture of the appearance of the growing plant.

In favour of certain so-called species of *Lepidodendron* having been the young state, or the branches, of the older *Sigillariæ*, it may be urged, that though abundant along with the latter genus, they are very seldom found erect, or as it were growing, that there is no real line of distinction between the two genera, and that some plants may be indiscriminately referred to either. Opposed to this theory, however, is the fact, that the *Sigillariæ* seldom or never show any tendency to ramify, or present scars of fallen branches.

Above the sudden enlargement of the base, this genus presents a columnar trunk of nearly equal diameter, very different from the gradually tapering *Lepidodendron*, and more like the caudex of a tree-fern. The great size and peculiar form of the scars also rather resemble those left by the fall of a frond than by a leaf such as the *Lepidodendron* bore. Another fact, favouring this view of their having simulated modern tree-ferns in mode of growth, is the absence of any hitherto recognized specimens of very small *Sigillariæ* which, from being of considerably less diameter than the old, would answer to the young † of that genus, and also the absence of slender *Stigmariæ* roots. In short, it ap-

* This remarkable case of an erect fossil many feet long having deposited around it as many feet of sandstone, followed by underclay, a bed of coal, shale, and other successive deposits, is a startling proof of the rapidity with which the coal-beds were formed, of the rapid decomposition of those which constituted the coal in comparison with the coniferous wood, and of the probable composition of that deposit of very soft tissued plants.

† This absence of young specimens may be otherwise accounted for by supposing on the one hand, that the shale deposit was drifted, and that the old specimens alone withstood the effects of the transport; and on the other, to me more probable, hypothesis, that they grew on the spot, and the older specimens alone fell and were fossilized. I was once inclined to consider some of the *Lepidophylla* as the foliage of *Sigillariæ*, but the specimens I have seen of certain fossils with those attached, and the figure given by Brongniart, "Hist. Veg. Foss.," vol. ii. t. 23, fig. 6, are against this supposition.

pears far from impossible, that the *Sigillariæ* was strictly Acrogenous (increasing not laterally but in length) in its growth, that it at first assumed nearly its full diameter, as a tree-fern or palm does, throwing out at the same time its stout *Stigmariæ* roots, which we know to be of a very uniform diameter in all stages, and throughout their whole length (points which will be dwelt upon in a separate essay). It may further be conjectured, that the *Sigillaria*, as it grew upwards with some rapidity, threw off the lowest fronds successively, leaving the broad scars on the stems.

I do not attempt to enter into any further or more rigid comparison between tree-ferns and *Sigillariæ*, confining the above only to what may subsist between the mode of growth of these two very distinct tribes of plants, which does not necessarily indicate a close botanical affinity between them.

The succulent nature of the *Sigillariæ*, which I have elsewhere dwelt upon, can hardly be considered an objection to these trunks having been the supports to the fern fronds* so abundantly scattered about their roots; for it may be remarked, that the *stipites* (stems of the fronds themselves) appear to have been of a succulent texture likewise, if we may judge of their invariable compression in the shales, and the rarity of their occurrence in the nodules of iron-stone, &c., in a state that shows structure. Succulent caudices (subarborescent) and stipites, too, are further characteristic of some of our largest and most coriaceous-fronded recent ferns, as the *Marattiaceæ* and *Daneaceæ*. In these tribes, the succulence of their organs is remarkably contrasted with the woodiness of those of most other ferns, the fronds of which are already assumed (on characters drawn from the fructification only) to occur in the coal formation.

A yet more remarkable and anomalous structure in *Sigillariæ* than either that of their stigmaroid roots or fluted stems was pointed out to me by Mr. Binney, of Manchester, to whom I am mainly indebted for all I know of the most important features of this genus, and whose investigations of their habit, mode of growth, and of their connexion with the *Stigmariæ* are beyond praise.† This is the curious crucial mark

* This is, I believe, the opinion of Mr. Binney, who mentioned it to me with some hesitation arising from his never having found the fronds attached, and from his having had no opportunity of comparing the *Sigillariæ* with existing tree-ferns.

† In the Manchester Museum there is a room almost entirely devoted to illustrating the botany of the coal formation. The original specimens of some *Sigillariæ* and models of others of the natural size, collected and transported with great labour, and arranged under Mr. Binney's direction, present to the eye the grandest features of the coal flora. Accustomed as I had been to see these fossils *in situ*, both in the pits and in quarries, I had previously no adequate conception of their gigantic size, nor of the rapidity with which coal may have been formed, if the tissues of these vegetables were as lax as I suppose them to have been.

which quarters the base of the trunk. The *Sigillaria* generally divides into four main roots at the base, which unite to form that crown of the dome described by Lindley and Hutton; and it is along the line of union of these four roots that these strongly marked lines run, all meeting at the centre of the dome. I know of nothing analogous to this either in recent or fossil botany.

Of the foliage of *Sigillariæ* little or nothing is known; the *S. lepidodendrifolia* * not appearing to be a typical, if at all a species, of the genus. The scars are, especially in the larger species, much too broad to be regarded as the point of attachment of leaves like those of *Lepidodendron.*

Internal Structure of Sigillariæ.—The beautiful plate and excellent description of the anatomy of *Sigillaria elegans* given by M. Brongniart † are, though as regards the specimen most satisfactory, far from completing our knowledge of the genus. The drawing of the entire plant is evidently not that of a fluted *Sigillaria* of the common form. It may belong to a young plant of this genus upon which the organs indicated by the scars were very closely packed; but this is a supposition only; and until the figured fossil is better known, or some of the fluted species are found to contain structure, we must hold that the tissues of *Sigillaria* proper are to be described. M. Brongniart's plant is no doubt allied to this genus, and very distinct from *Lepidodendron:* there is a probability, too, of its belonging to the same plant as *Stigmaria*, which is evidenced by the similarity of the arrangement of the vascular tissues in both. This tissue in *Stigmariæ* is broken into wedges, indicating a higher organization than is found in *Lepidodendron*, and a still more complex arrangement in the trunks of which *Stigmariæ* are the root. Such we find in M. Brongniart's *S. elegans*, wherein are two distinct series of bundles of vascular tissue; one disposed in wedges separated by medullary ? rays,‡ the other in as many bundles, each placed at the back or small end of one of these wedges.

The great bulk of *Sigillariæ* seems to have been inimical to the preservation of their tissues, the process of decay being generally effected on a grand scale in the substance of a plant evidently almost entirely composed of a lax tissue. The remains of a central column are, however, sufficiently obvious in the upright stems of many *Sigillariæ*,

* "Brongn. Hist. Veg. Foss.," p. 426, t. 161.

† "Archives du Musée d'Hist. Nat." vol. i. p. 404.

‡ The tissue of the axis of this plant and of its rays is wanting. This is generally the case in the spaces corresponding to what are filled with cellular tissue in analogously formed vegetables. In all carboniferous fossils that I have examined the cellular tissue is best preserved at the coaly circumference. I have, however, observed it elsewhere; and in one *Stigmaria* it occupies nearly all the broad space intervening between the circumference and vascular column.

these have been called "*Endogenites*," are scarcely two inches in diameter, and are generally obliquely placed in the substance of specimens five feet and upwards in girth. That this slender column represented all the vascular tissue of this plant, I cannot doubt, from examination of *Stigmariæ*, whose vascular column often assumes the same appearance.

Affinities.—These have been very much discussed by various naturalists, who have eagerly seized upon the few botanical characters the very imperfect fossils present.

In noticing its outward appearance, little allusion was made to the *S. lepidodendrifolia*, the only species of the genus whose foliage has been described, and which, if really a congener of *S. Organum*, &c., would, doubtless, ally all these plants closely to *Lepidodendron* itself. But I am inclined to pronounce M. Brongniart's figure of this plant* to be a true *Lepidodendron*, though possessed of scars more resembling those of many *Sigillariæ*, for it wants the fluted stem. The leaves of this *S. lepidodendrifolia* seem to be what was considered a species of grass or sedge, and placed in the genus *Cyperites*.

Did the great *Sigillariæ* bear leaves like those of *Lepidodendron*, they could hardly escape petrifaction in the shales, especially where the *Cyperites* so abound; but there is nothing whatever in the shales which we can recognise as having been in any probability an organ of or appendage to *Sigillariæ*.

Fig. 11.

One point which must not be overlooked, namely, the possibility of the scars upon young *Sigillariæ* being quincuncially or spirally arranged, as in *Lepidodendron*, and afterwards owing to the dilatation of the trunk being disposed in lines. The reverse of this is sufficiently obvious in some recent *Coniferæ*, as the *Pinus Webbiana*, where the young leaf-scars are disposed in parallel lines, which become disturbed through age, and appear ultimately arranged in the old branches, as shown in the accompanying wood-cut (Fig. 11).

That there are *Lepidodendrons* generically distinct from *Sigillariæ* cannot be doubted; for specimens of the former genus, many feet long, are known, having their scars spirally arranged throughout; but this is not inconsistent with the hypothesis that other plants in a certain state, apparently belonging to the

* *Sigillaria lepidodendrifolia*, "Brong. Hist. Veg. Foss.," vol. ii. t. 161.

one genus, ought really to be referred to the other, and that the *Sigillaria elegans*, whose structure M. Brongniart has ably illustrated, may be amongst them.

Although the *S. elegans* here referred to displays no fluting, it is possible that in an older state it might, and that the arrangements of the vascular tissue into separate wedge-shaped bundles, may indicate such a fluting, each ridge answering to one of the wedges; a conjecture the more probable, from the mass of vessels which supply the leaves, and which lead to scars on the ridges being placed exactly opposite to the wedge-shaped bundles.

The opinions previously held of the affinities of *Sigillariæ* are very various, and no less vague, being grounded upon supposed resemblances in their external characters, to certain natural orders of living plants. Thus Artis*, Lindley, and Hutton,† and more recently Corda,‡ have referred them, with more or less confidence, to *Euphorbiaceæ*.

Schlotheim § to *Palmæ*.

Von Martius to *Cacti*.

Brongniart, originally, || and

Sternberg to *Ferns*.¶

In the earlier years of the study of fossil plants, when their affinities were scarcely known, it was no wonder that observers sought the affinities of *Sigillariæ* amongst *Dicotyledones;* but now that each successive observation tends to prove that every order of that class,** except *Cycadeæ* and *Coniferæ*, were absent from the coal-fields, it is not a little bold to persist, as M. Corda has done, and on very insufficient grounds, in ranking them among *Euphorbiaceæ*. The absence of true woody fibre in any part of these plants, pointed out by Mr. Bunbury†† is conclusive against *Sigillariæ* being allied to *Euphorbiaceæ:* I may add, that the same objection affects M. Corda's reference of *Lepidodendron* to *Sempervivеæ*.

Their reference to *Palmæ* by Schlotheim, is yet more unsatisfactory. The central column is of itself a fatal objection, and it is further exceedingly improbable that such numerous *Palmæ* would be petrified without the occurrence of structural specimens.

The arguments in defence of their being *Cacti* are nearly what other writers have thought conclusive as to their being *Euphorbiaceæ*.

* Artis, Antediluv. Phytol., t. 3, 10, 18.

† Lindley and Hutton, Fossil Flora, I. pp. 94—110; t. 31—36; II. p. 13; III. p. 47, t. 166.

‡ Corda, Flora der Vorwelt, p. 34.

§ Schlotheim, Essai, p. 23, t. 12.

|| Brongniart, Mem. Mus. d'Hist. Nat., v. 8, t. 1, f. 7.

¶ Sternberg, Vers. I. p. 4, t. 38. Vers. II. p. 209, t. 15.

** See M. Brongniart's excellent remarks on this subject in the "Annales des Sciences Naturelles," 3rd Series, vol. v. p. 52.

†† Quarterly Journal of Geological Society, vol. ii. p. 120.

Judging from the great preponderance of *Filices* in the coal measures, the probabilities are somewhat in favour of *Sigillariæ* belonging to that class; and this opinion has accordingly the most advocates. Lindley and Hutton* indeed adopted it at first, but rejected it afterwards on the examination of *Caulopteris;* † a most decided tree-fern.

The latest observations, however, on this subject, are those of M. Brongniart, who after an examination of the *S. elegans*‡ slightly modifies his opinion, placing the genus between *Lycopodiaceæ* and *Cycadeæ*, but nearest to the latter.

Assuming the *S. elegans* to be a true *Sigillaria*, it appears to afford slender grounds for the adoption of the above view, as regards its uniting such diverse and distinct orders as *Cycadeæ* and *Lycopodiaceæ*. It is true that it departs signally from the ordinary structure of the latter order, which however itself exhibits various modifications of the arrangements of scalariform tissue; but it requires stronger evidence than the more perfect structure and regular arrangement of the bundles of vascular tissue to ally it to *Cycadeæ*, with which, in general appearance, habit, fluting, markings, stigmaroid roots, absence of accompanying foliage, and many other points, it has nothing in common.

The *Cycadeæ,* on the other hand, and especially the *Zamia integrifolia*, which M. Brongniart instances as peculiarly favourable to his views, possess broad vessels perforated with very large circular apertures § (not seen in *Sigillariæ*), and they want the double zone of bundles of vascular tissue and diverging fascicles of *Sigillariæ*.

That the *Sigillariæ* were allied to *Lycopodiaceæ* is evident, their tissues and scarring being very like those of *Lepidodendron,* in which, however, there is but one series or zone of vascular tissue. In both, the great mass of the woody axis is formed of large tubular vessels identical in structure, and in both, fascicles are given off from the central mass to the scars on the circumference, which fascicles consist of slenderer tubes than the axis does. In *Lepidodendron* there are no medullary rays, the vascular zone being continuous and surrounded by

* Fossil Flora, Introduction to, vol. i.

† Fossil Flora, tab. 42, sub *Caulopteris primæva,* et tab. 54, sub *Sigillaria pachyderma.*

‡ Archives du Muséum, t. i. p. 426.

§ A very similar tissue is exceedingly common in the coal-beds: all the mineral charcoals (commonly called mother-coals in S. Wales) present it abundantly, and appear wholly formed of such vessels held together by fragments of medullary rays. In specimens of charcoals from the Virginian coal-mines given me by Mr. Lyell, the same tissue occurs; but it was only during the passage of this sheet through the press that I had the good fortune to meet with a fragment of the fossil wood to which these charcoals belong. In examining the collection of Mr. Darker, an acute observer and excellent lapidary, he showed me relics of a small rolled nodule of fossil wood from the coal-seams of the Yard Mine, Durham, in which I at once recognized this tissue, of which I had been long in search. The nodule was little larger than a hasel-nut, and originally covered with quartz crystals Mr. Darker had himself conjectured its probable alliance to *Cycadeæ.*

those slender vessels from which the fascicles diverge and run to the scars. In *Sigillaria elegans,* again, there are medullary rays; and M. Brongniart states that the fascicles which run to the scars in that plant originate in the inner zone of slender vascular tissue. I am however more inclined to suppose that they belong to a system of vessels exterior to the main body of the woody tissue, for if they passed out by the medullary rays they would be alternate with the latter, instead of being placed immediately opposite to them.

In *Stigmariæ* the bundles of slender vessels are distinctly seen arising from behind the woody zone and passing out by the medullary rays to which they are opposite, not alternate, as in *Sigillaria elegans.*

It is not by solitary characters, and least of all by such as the arrangement of the tissues in the axis affords, that genera of plants are referred to their natural orders. Amongst recent plants we see many instances of plants indisputably belonging to one natural family having the peculiar woody tissues of another and far distant group in the system; but these are mere analogical resemblances and by no means indications of affinity.

We may conclude then that the *Sigillaria elegans* was not far from *Lycopodiaceæ*, and especially from *Lepidodendron:* — that it was of much completer structure and higher organization than either is incontestable; but the indications of a relationship with any individual group higher in the series, or with *Cycadeæ* in particular, appear to me far too feeble to justify our considering it as tending to unite these two natural orders. It is a plant which (until we know its foliage or fructification) must be considered as belonging to the great family of ferns (including *Lycopodiaceæ*), displaying a relationship, though only of analogy, to *Cycadeæ* in one point, and to *Euphorbiaceæ* and *Cacti* in others.

Lepidodendron. — The anatomy of this genus has been well illustrated by Lindley and Hutton,* by Witham,† and more recently by M. Brongniart,‡ whose analysis has left little to be desired regarding the structure of its stem. Under the remarks upon *Lepidostrobus* which follow this Essay will be found notices of a few remarkable points connected with the occurrences of cylindrical specimens of the trunk of this genus containing cones in their hollow axes; and of the sculpture of its surface as it appears before that compression to which the specimens are almost invariably subjected previous to or during their petrifaction.

Of the stems, branches, leaves, and fructification, we have thus a very satisfactory knowledge; but the nature of their roots is not ascertained. Mr. Dawes, of West Bromwich, to whom I am indebted for much information regarding the structural characters of coal-fossils, is

* Lindley and Hutton. † Witham. ‡ Brongniart.

inclined to regard the species of *Halonia* as roots of *Lepidodendron*, on which opinion I have no remarks to offer.

Nearly forty species of *Lepidodendron* are described; and the characters of the majority of them are drawn from the arrangement and form of the scars on the stem. There are, besides, seven or eight species of *Lepidostrobus*, some of which (perhaps all) are parts of one or other of the *Lepidodendrons*. *Halonia*, another genus of the *Lepidodendreæ*, is composed of three species, possibly the roots of these or others of the same genus. Some *Lepidophylla* are certainly its leaves: a few of the carboniferous *Lycopodites* are founded on its slender terminal branches; and one or more *Trigonocarpi* (as I shall show in some remarks upon *Lepidostrobus*) are probably the seed-vessels (sporangia) of the same.

This reduction of genera to species, and in some cases of genera contained in one order (as *Trigonocarpum*, which is placed in *Scitamineæ* by Unger) to the species of another, materially diminishes our ideas of the great amount of species preserved in the coal. Such a reunion is not, however, available in practice, nor is it here for the first time forced on our attention; though it is not sufficiently considered, in the hurry of describing new forms, that the result of further discoveries amongst those already described, is to reduce the many supposed species to fragments of a few certain ones. Hence, the object of the fossil botanist should be now, in preference to describing what appear new species, and thus increasing the synonomy, to throw more light on the old, about *all* of which we know, botanically speaking, very little.

But it is not merely by the reduction of genera, founded on the parts of plants, that this is to be carried into effect. No one accustomed to study existing individuals, can regard the characters adopted for distinguishing the *Lepidodendrons*, without comparing their validity with those drawn from the same parts of their living analogues. Applying this rule to *Lepidodendron*, it will be seen that if the species of that genus were as prone to vary in the foliage as are those of *Lycopodium*, our available means for distinguishing them are wholly insufficient. Take, for example, the noblest of the genus *Lycopodium*, the *L. densum* of New Zealand, which in stature, and probably in general habit, &c., approaches nearer to *Lepidodendron* than any of its congeners. In this species, not only do the shape and arrangement of the leaves vary in different specimens, but leaves from different parts of the same individual are very unlike. The three accompanying cuts represent as many states or varieties of this plant, gathered by myself in New Zealand, where multitudes of specimens of all were growing intermixed. Of these, the dense fastigiate one (Fig. 12) is the most common; and

this is represented with the cones at the ends of the branches, borne as the *Lepidodendrons* did theirs, and all of a uniform size.* The same variety, however, repeatedly occurred with some of its branches, as in (Fig. 13), clothed with slender patent squarrose leaves ; whilst others had

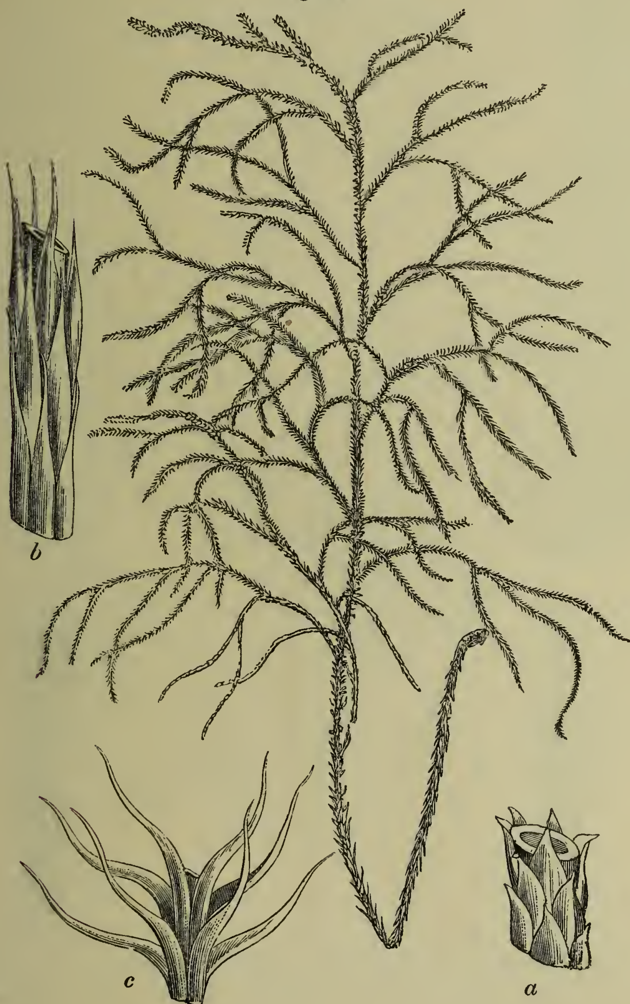
Fig. 12.

the branches slender, as in (Fig. 14), and covered with small and closely appressed leaves. In figure (13) the whole habit is widely different; and the leaves from three parts of the plant are so dissimilar, that had

* Though this species bears cones whose size, shape, &c., is constant, the majority of the species are extremely variable in this respect, as were the *Lepidostrobi :* this is illustrated in my remarks on the latter genus.

we only portions of branches, &c., such as we possess of *Lepidodendron*, it were impossible to recognize the plant. At letter *a* is shown the base of the stem, covered with closely imbricating leaves; at letter *b*, a portion from the middle, with very long tapering appressed leaves; at letter *c*, the branch, with its elongated spreading and squarrose foliage.

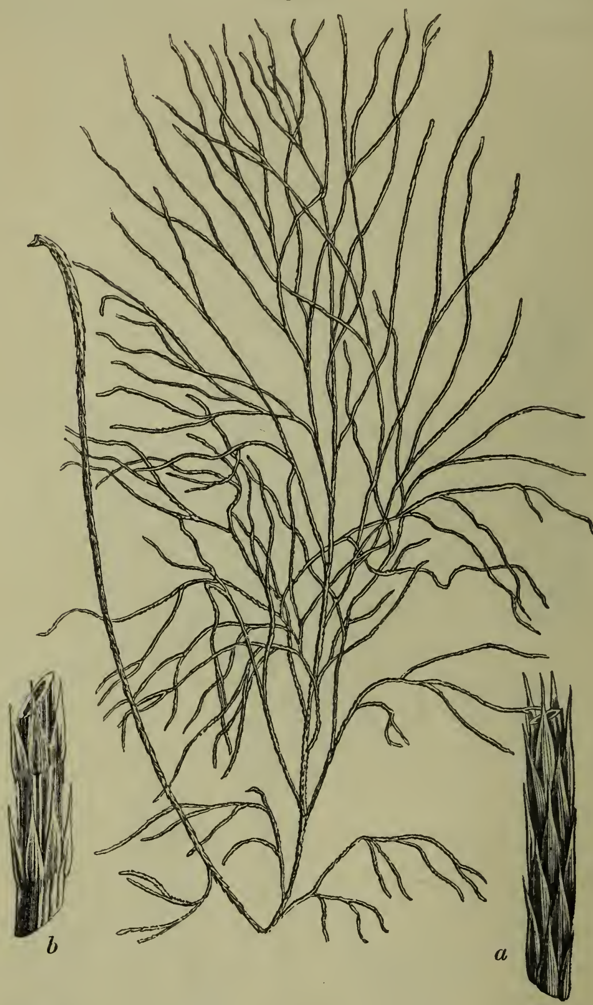
Fig. 13.



The third modification of this plant is represented at (Fig. 14), in which the branches are uniformly slender, and clothed with similar appressed leaves throughout; but the arrangement of these leaves is exceedingly variable; for at letter *a* they are closely imbricated and cover all the

stem, whilst at *b* they are disposed in whorls, separated from one another by more than the length of the leaf itself.

Fig. 14.



It may well be asked how the botanist can pronounce these dissimilar forms to belong to one plant. This can only be done by comparing a large series of perfect specimens, or by growing the different varieties from the seeds of one. The plant has, however, some constant characters and a certain habit, the value of which is at once perceived and admitted by the skilful botanist, though the uninitiated eye cannot seize it.

Ulodendron.—This very remarkable genus scarcely differs from *Lepidodendron* in internal structure: its external aspect widely departs from that of any plant, recent or fossil, with which I am acquainted. I have seen in collections, specimens which have been fossilized, apparently erect, or at any rate, under very different circumstances from those preserved in the shales over the coal. They present the appearance of a large unbranched zigzag trunk, with two rows (opposite one another) of alternating cup-shaped deep depressions, one at every projecting angle of the trunk. Some idea of the appearance of these specimens might be gathered from the accompanying wood-cut. Mr. Dawes showed me a specimen preserved in sandstone, with a large organ which he considers to be a cone inserted into one of the cup-shaped depressions. I could not, however, form any conclusion concerning the real nature of this highly interesting example.

Fig. 15.

Knorria. — A genus of which very little is known. Dr. Lindley* pronounces the *K. taxina* to be certainly coniferous, comparing it with a leafless branch of the common Yew; to me it appears to have quite as much resemblance to the stem of a *Lycopodium*, especially of *L. phlegmaria.*†

The *K. Sellonii* again, is remarkably similar to what I have considered as much compressed specimens of *Stigmaria ficoides*, which are very much compressed but not entirely flattened, and in which the cellular tissue has collapsed, leaving the vascular bundles which meet the circumference at the areolæ projecting beyond the surface:—this, however, is only a suggestion.

Calamiteæ.

I have in vain sought for any traces of structure in carefully prepared species of this genus; or for evidence of their being *Equisetaceæ* in the presence of those siliceous stomata with which that order abounds, and which would surely have been preserved in the fossil state.

Very fine specimens of this genus were pointed out to me on a cutting of the Manchester and Bolton Railway by Mr. Binney: they were

* Lindley and Hutton, Fossil Flora, sub. *K. taxina*, tab. 95.

† Compare the figure of the stem of this plant given in Brongniart's Hist. Veg. Foss., tab. 7, fig. 11, with Lindley and Hutton's figure v. 2, t. 95.

standing erect as they grew in a forest of *Sigillaria*, distinctly proving that what have been taken for leaves by the authors of the Fossil Flora, are in reality roots.

M. Brongniart* ranks them, I am not aware upon what ground, with dicotyledonous plants, allied to *Lepidofloyos*, whose tissue has been illustrated by Corda.

Cycadeæ.

The only evidence I have seen that this order existed during the carboniferous period, rests on that afforded by the charcoal (or mother-coal), and rolled nodule of fossil wood, both alluded to at p. 421; and it is confirmed by the curious observations of Brongniart † upon *Noggerathia.*

On the Order *Coniferæ*, and some obscure ones supposed to be allied to *Filices*, I have no remarks to make: future collectors will doubtless throw some light upon their true nature, especially when it is considered how much these last few months have done for the *Lepidodendrons*, *Lepidostrobi*, and *Stigmaria.* Our provincial collections, and even the still rudimentary one of the Geological Survey, abound in specimens suggestive of most interesting points, yet to be worked out. These, it is trusted, will form the materials for a succession of essays in the Memoirs of the Geological Survey of the United Kingdom.

I cannot conclude these desultory, and I fear unsatisfactory remarks, the fruits of one short year's study in the vast field of inquiry to which they relate, without expressing a hope, that my observations on the discouraging aspect of the science will not deter the beginner from pursuing his investigations: still less that they will lead the geologist to reject such information as the botanist can supply, because it has hitherto been encumbered with loose speculations on the affinities of the genera, distribution of the species, and value of the characters which the latter display. Too much has been expected from the botanist, who wants materials for those bold generalizations which the fossils of the animal kingdom so abundantly supply. Except to individuals who have great facilities for this study, the collection and examination of the waifs and strays of a by-gone Flora is a forbidding pursuit. It can be undertaken to advantage only by him to whom the existing Flora is in some measure familiar, and such an one cannot see the rapid advances in palæontology which are due to the exertions of the zoologist, without feeling a conviction, that some undistinguishing geologist will expect more definite and immediate results from his labours than the specimens at his command may ever afford.

* Brongniart, Annales des Sciences Naturelles, Ser. 3rd, vol. 5, p. 52.

† Brongniart, Annales des Sciences Naturelles, l. c.

The very desire to give a definite answer to the many puzzling questions proposed to the observer, has mainly increased the prevailing readiness to draw arbitrary conclusions from the characters which the outward appearance of a fossil affords: against this the student cannot be too frequently warned. The earliest inquirers saw (and some see still) the acorn, bean, hasel-nut, &c., in the strata of the coal formation, parts of plants belonging to orders which are not acknowledged by the sober geologist to have existed at that period. So the rude collier, denying a vegetable origin to the ferns of the shale, beholds in them merely the effort of a creative power which has fashioned stones in the likeness of plants; whilst his more reflective master recognizes fossil snakes in *Lepidodendron* and mail-clad crocodiles in *Sigillariæ.* He who acknowledges all to be vegetables has advanced a step further, but there he too may stop, if he does not pursue his investigations with due caution; for the measure of success which will reward his study will be proportionate to the comprehensiveness of the view he takes of the whole vegetation of the period in question, whether such view be the result of his own experience, or adopted from the conclusions of others. Let him remember that as remote districts on the globe are peopled, not only by different species of plants but by different prevailing natural orders, so the outward forms of one locality are imitated in the other by objects which have no further relationship, and nothing else in common. In this respect, intervals in time are marked by the same changes as intervals in space. Let him likewise bear in memory, that the two most experienced and distinguished observers have attained the same conclusion regarding the general features of the coal Flora, which I shall give in their own words. Goeppert,† in his resumé of the characters and affinities of *Stigmariæ*, says:—

" ———— d'ou s'ensuit une nouvelle preuve pour l'opinion deja emanée tant de fois, que la vegetation actuelle et la primitive ne forment q'une seule Flore, dans laquelle les familles separées forment actuellement un ensemble harmonieux, au moyen de formes intermediaires multipliées qui se trouvent tantot dans le monde actuel, tantot dans le monde primitif."

M. Brongniart, the most successful cultivator of the science, after a careful review of the whole vegetation of the coal, excludes all existing orders of flowering plants except *Coniferæ* and *Cycadeæ*, and thus concludes his essay on *Noggerathia*:— ‡

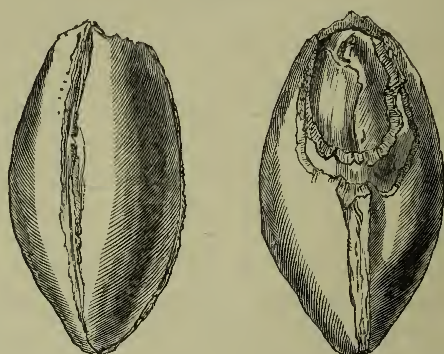
* The tail-piece represents a very singular fossil fruit of the coal formation, possibly belonging to the highest order of plants of any known during that epoch. It was discovered by Mr. Wilson, of Barnsley, in the Oak's Quarry sandstone, and is apparently the *Trigonocarpum ovatum*, Lindley and Hutton (Fossil Flora, t. 142 A.)

† Goeppert, Genera des Plantes Fossiles, under *Stigmaria,* p. 29.

‡ Annales des Sciences Naturelles, Ser. 3, vol. 5, p. 61.

" Ainsi, tout semble nous porter à conclure, des recherches faites jusqu'à ce jour, que la végétation terrestre de l'epoque houillère était limitée a deux des grandes divisions du regne végétal ; les Cryptogames acrogènes ou vasculaires, et les Phanérogames dicotylédones gymnospermes."

Fig. 16.



On some Peculiarities in the Structure of STIGMARIA. By Dr. HOOKER, F.R.S., &c., Botanist to the Geological Survey of the United Kingdom.

MUCH as has been said and written upon the structure and appearance of *Stigmaria*, and long as this genus has been recognized as the prominent feature in all discussions regarding the origin of coal, there are still some very important points in its history which have hitherto escaped observation. Of these, the most remarkable is the nature of the surface previous to compression, and of the bases and attachment of the rootlets.

The surface of the *Stigmaria* has hitherto been supposed to be nearly even and uniform, interrupted only by shallow scars, variously described as circular by some, oblong by others, and lanceolate by still a third class of observers, according to the state of the specimens they have examined. The depth of these scars seldom exceeds $\frac{1}{10}$th to $\frac{1}{8}$th of an inch, in which respect the appearance of the surface of this fossil is so constantly the same, that no geologist has at first sight recognized the specimens figured at Plate 1, as belonging even to the genus *Stigmaria.*

The above-mentioned two specimens are fragments of plants which have evidently been preserved under little or no compression: the perfectly circular outline and uniform depth and figure of the cavities, together with the cylindrical form of the organ they contain, all attest this positively; whilst the depression of the surface between these cavities, and the wrinkled substance, seem to indicate that a slight collapse of the tissues composing the plant has taken place.

After having convinced myself that the specimens of *Lepidodendron*, figured at Plate 8, fig. 12, and that the portion of bark enclosed in the fossil,* Plate 10, fig. 7, and indicated by the daggers, were the only specimens that had come under my observation displaying any approach to the original and unmutilated state of that genus, I was more than ever assured of the extreme laxity of the tissues of the coal-plants, and persuaded in my own mind that the ordinary run of specimens of all were calculated to lead to erroneous views of their original appearance. Being thus prepared to find familiar forms under a new aspect, I was not a little gratified, when inspecting the cabinet of Miss Jukes, of Birmingham, to recognize the specimen of *Stigmaria ficoides*, figured at Plate 1, fig. 3, and which was obligingly lent for the use of the Survey. On my return to town I found that a similar, but more perfect and much

* See Memoirs of Geolog. Survey, in Essay on *Lepidostrobus.*

larger, specimen had been sent to the Museum, by Mr. Ormerod, and figured for me by Mr. Baily. In this latter the cavities are of somewhat less diameter, and contain the obconical or flaggon-shaped bases of the rootlets, whose summits are level with the mouth of the cavity, and are depressed at the apex.

In neither of these cases could I gain any information upon the particular circumstances under which these valuable specimens were preserved, to which however they must owe their singularly perfect condition. The precise locality of the specimen, Fig. 3, is unknown: Mr. Ormerod's was found overlying the white coal in the Peel Quarries, Lancashire.

Comparing these with the usual state of the plant, figured at Plate 2, fig. 4, the amount of collapse of the tissue which shall bring the base of a cavity a full half-inch deep, to the surface, must appear startling; but it is not really so remarkable as that the whole cylinder, including the vascular axis, should be reduced by pressure from the thickness of three or four inches to that of an inch, or even a few lines, or to a mere flake, as is generally the case with this plant when preserved (if this deserves the name of preservation) in the shales above the coals.*

While upon this branch of the subject I may allude to the singular difference in the appearance of the surface in different parts of the same *Stigmaria*. In the Bolton railway trees, to which Mr. Binney conducted me, the *Sigmaria* roots extended uninterruptedly for upwards of 20 feet, and at different points along that distance from the trunk of one individual we had many opportunities of marking the appearance of the surface: this, which was characteristic of *S. ficoides* throughout the greater part of their length, when within a few feet of the tree was seen to be materially altered. The roots themselves here became broader, more vertically compressed, the scars densely packed, and forming transversely elongated areolæ, the fossil thus possessing all the characters of *S. conferta* of Corda.†

Though so much swollen below, the surface of attachment between the base of the rootlet and of the cavity into which it is inserted must have been but limited and the union slight; for in several instances these organs are loose in the cavity, and resemble so closely a nut in its shell, that this fossil has been taken for a fruit with many nuts borne on a pitted receptacle. In the admirable and very complete account of the genus, published by M. Goeppert,‡ there is a figure (Table XIII.), representing the outline of the rootlet as produced within the

* The *Stigmaria* is rare in the shales above the coal; but I have observed it to occupy that position in the Oakwood level of Cwm Afon (in S. Wales). I have elsewhere (p. 396) given my views on the subject of the prodominance of this vegetable in the underclay.

† Corda, Flora der Vorwelt, Tab. 13.

‡ Goeppert.

circumference of the stem, and circumscribed by a dark line : this line probably indicates the surface of the deep cavity, to the base of which the rootlet is attached.

The apices of those bases of the rootlets are marked with a circular depression, and so is the lower extremity of the rootlet figured at Plate 2, fig. 1, suggesting the possibility of the point of the latter (rootlet) having been jointed unto the basal portion, at the level of the aperture through which it emerges from the root. These corresponding depressions may, however, have been caused by the collapse of the cellular tissue at the fractured end, and thus indicate no articulation at all. In none of M. Goeppert's figures is any such articulation represented, but there is something of the sort in Corda's Tab. XII., Fig. 4.

For the highly interesting specimen of a rootlet in which the cellular tissue is preserved, the Museum is indebted to Mr. Warington Smyth (Mining Geologist to the Geological Survey). It is figured at Plate 2, Fig. 1, and consists of the silicified lower portion of a rootlet, whose sides have collapsed, so as to reduce its originally cylindrical form to that of an irregularly four-sided prism. The substance is formed of a network of exceedingly delicate cellular tissue, (Plate 2, Figs. 2 and 3,) composed of hexagonal cells ; and it is traversed throughout its length by a dark line, (Fig. 2 *a*,) no doubt indicating the prolongation of one of those slender bundles of vascular tissue which issue from the medullary rays of the axis, (*a* of Figs. 6 and 7,) and thence proceed to the mamillæ on the surface of the specimen, figured at Fig. 4, or the bases of the cavities in the figures in Plate 1.

This very simple structure of rootlet is similar to that of several *Lycopodia*, and indeed of many other plants, both Monocotyledonus and Dicotyledonus, so far as can be ascertained without a further knowledge of the axis of the organ ; of whose structure, however, there can exist no reasonable doubt, since it may be confidently assumed to consist of a bundle of vessels, similar to those represented at Fig. 7 *a*.

In M. Goeppert's* figure (Table XIII. Fig. 8, E *d*) this axis is represented as formed of such tissue, surrounded by cellular tissues disposed in two concentric rings, between which a black line is interposed. There is no appearance of any similar arrangement in the specimen I have examined, the net-work being continuous from the vascular axis to the circumference. As there appears to be a rupture of the tissue to a considerable extent in M. Goeppert's figure near this line, and as where there is no such disunion the cellular tissue is continuous across the line, I am inclined to regard the latter as a coaly deposit, consequent possibly upon the process of petrifaction having been arrested at that point.

Mr. Henry Beckett of Wolverhampton having forwarded to the Geo-

* Goeppert, l. c. t. xvi. fig. 48.

logical Survey most beautiful specimens of the vascular axis of *Stigmariæ*, they were sliced for examination by Mr. Cuttle, and some of the points they perfectly illustrate are drawn by Mr. Bone.

Plate 2, fig. 4, represents the surface of the specimen in which the axis Fig. 14 is contained. There was not the slightest appreciable distinguishing characters between the markings of this and that specimen containing the very different looking axis Fig. 5. I shall therefore describe them as specifically the same, for in microscopical characters also they are identical.

The axis consists of a broad cylinder, composed of parallel elongated tetragonal or hexagonal tubes, of equal diameter throughout, for the greater part of their length obtuse and rounded at either extremity, and everywhere marked with crowded parallel lines, which are free or anastomising all over the surface. The tubes towards the axis are of the smallest diameter: they gradually enlarge towards the circumference, where the largest are situated, though bundles of smaller tubes occasionally occur among the larger (Fig. 7 *d*). The cylindical axis (which may for convenience be called the woody system of the plant) is divided into elongated wedge-shaped masses, rounded at their posterior or inner extremity by numerous medullary rays of various breadths, some much narrower than the diameter of the tubes, others considerably broader, but none are conspicuous to the naked eye, except towards the outer circumference.

The medullary rays, even the narrowest, are traversed by bundles of tubes half the diameter of the largest vessels of the axis (or wood) or even less (Plate 2, figs. 6, 7 *a*, and 8.) The transverse lines on their surface are generally finer and less crowded. These bundles evidently originate in the cellular axis of the stem, and do not belong to the wedges of vascular tissue (or wood) between which they run, as they appear to have done in M. Brongniart's* specimen of the plant, both from his figure and description. I cannot, however, but conclude the latter to be erroneous, because M. Goeppert, whose specimens appear to have been in this respect more perfect than any hitherto, illustrated, represents the bundle of vessels which proceed from the axis, run between the wedges of wood, and communicate with the rootlets (leaves, *Goepp.*) as originating in isolated bundles, irregularly scattered in the medullary axis of the stem. Of the existence of these bundles there are some indications in my own specimens, though for the most part they have been destroyed with the cellular tissue of the plant, which indeed often takes place with the system of vessels from which the leaves, rootlets, or scales of the cones in these fossils are supplied. It is so in the stems of *Lepidodendron*, in the axis of the *Lepidostrobi*, in the

* Archives du Museum d'Hist. Nat. v. i. p. 405, t. 29, f. 3 d.

portion of the *Sigillariæ* figured by M. Brongniart, and in other fossils contained in the Museum of the Survey, and is probably owing to their great delicacy, for they are much more membranous in appearance than the similarly marked vessels of the wood.

The most important circumstance thus developed is the existence of a double system of vessels in *Stigmaria*, first shown by Goeppert, and the consequent approach in this respect to *Diploxylon*,* Corda. In *Diploxylon*, however, the inner system forms a continuous cylinder, concentric with and in juxta-position to the wedges of wood forming the outer; whilst in *Stigmaria* the same inner system is broken up into scattered bundles apparently unsymmetrically arranged in the medullary axis or pith of the plant.

In *Lepidodendron* again there is the same double vascular system; but that, from which the bundles arise which proceed to the leaves, is placed externally to the wood, where it forms a continuous zone with a well-defined inner edge (in juxta-position with the outer circumference of the inner zone) and a sinuous outer edge, from which the diverging bundles are given off. Such is also the arrangement in the axis of *Lepidostrobus*.

Sigillaria elegans differs from all the above. The woody system is (as in *Stigmaria*) broken up into wedge-shaped plates, separated by medullary rays; and another vascular system (from which, possibly, the leaves are supplied) forms † a series of bundles in the medullary axis of the stem, each placed opposite the wedges of wood. The bundles which immediately supply the leaves again are also placed opposite the wedges of wood, but externally to them, in this respect differing from *Stigmaria*, where they are opposite the medullary rays, and from *Lepidodendron*, where they form a continuous zone. It is, however, doubtful to M. Brongniart whether in his *Sigillariæ* the system of vessels which supplies the leaves really communicates with that immediately surrounding the pith. To me that structure appears improbable, from the position of both being alternate with the medullary rays through which the vessels should pass. This then is a very important point to clear up; for if the inner and outer bundles of tissue in *Sigillariæ* communicate through the medullary rays, then will the arrangement be nearly identical with that of *Stigmaria*. If, according to Brongniart's views, on the other hand, the outer bundles from which the leaves are supplied have no communication with the innermost, and form an independent

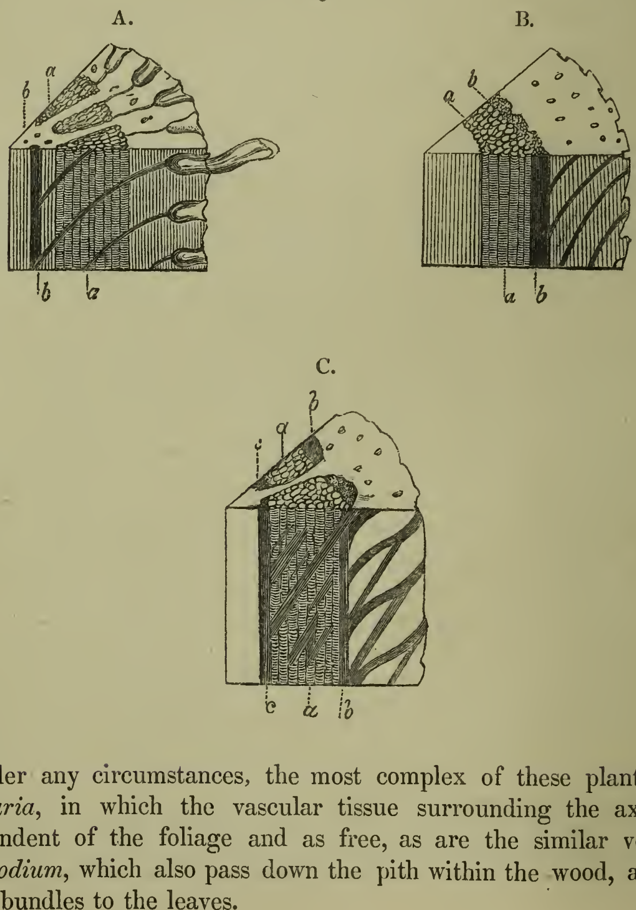
* Corda, Flora der Vorwelt, p. 34, tab. xi.

† On this point M. Brongniart is not satisfied, not having seen the bundles which traverse the cutical portion in the medullary rays, which might be expected if they communicated with the system of vessels within the wood and immediately surrounding the pith.

series concentric with but exterior to the wood, then will the arrangement coincide with that of *Lepidodendron* in these important points, and the *Sigillaria* in question may be pronounced a *Lepidodendron* with the vascular system broken up into wedges divided by medullary rays, and further possessed of a third system of vessels placed in juxta-position to and within that of the wood.

The accompanying wood-cuts explain these arrangements of the tissues in *Stigmaria* (A.), *Lepidodendron* (B.), and *Sigillaria* (C.), the latter both according to M. Brongniart's view, and in the light wherein I regard it. In all, the letter *a* indicates the vascular tissue of the wood; *b*, that from which the leaves are supplied; and *c* indicates the third series in *Sigillaria*.

Fig. 1.



Under any circumstances, the most complex of these plants is the *Sigillaria*, in which the vascular tissue surrounding the axis is as independent of the foliage and as free, as are the similar vessels in *Lycopodium*, which also pass down the pith within the wood, and send off no bundles to the leaves.

Should the conclusion of M. Brongniart hold good, and the vascular system of the axis *c* give origin to the bundles *b*, then will there be some botanical evidence of *Stigmaria* constituting a part of *Sigillaria*. If, on the other hand, it does not prove correct, still its failure would afford neither proof nor even presumptive evidence against these genera holding the respective place of root and stem.

As, however, I have elsewhere stated, I consider Mr. Binney's discoveries to be conclusive upon the origin of *Stigmaria*. That gentleman had the kindness himself to conduct me to the spot where the great fossil trees were, and we cleared the soil from the roots of several well-marked *Sigillariæ*, which roots were indisputably the plant called *Stigmaria*.

M. Goeppert, who holds this genus to be an individual plant, generically distinct from any other, refers it to the *Lycopodiaceæ* as its nearest allies, but suggests the probability of its being intermediate between that order and the *Cycadeæ*. This exact coincidence with the opinion of M. Brongniart respecting the affinities of *Sigillariæ* is sufficiently striking, especially since these authors entertain different views of the nature of *Stigmaria*. I have, under my general remarks on *Sigillariæ*, expressed doubts of the correctness of this opinion, in reference to the connexion of two such widely different families by so slender and fallacious a character as the arrangement of the tissues in the stem. The points by which *Sigillaria* (and *Stigmaria*) is allied to *Lycopodiaceæ*, especially through the *Lepidodendra*, are probably quite sufficient; but when we consider that the *Cycadeæ* have sexes, a complicated reproductive system, and a perfect seed with embryo, radicles, albumen, &c., whilst *Lycopodiaceæ* are asexual, have no reproductive system of male and female flowers, and increase by spores, it will be evident that it is by modifications of these important organs that the intermediate family would be indicated. The noble Tree-fern departs from its humble congeners in assuming the aspect of a Palm, and the *Cephalotus* (or Pitcher-plant of New Holland) has the leaf of *Nepenthes;* but the Tree-fern does not unite the Ferns with the Palms, and the *Cephalotus* is not the less a rosaceous plant because it has the pitcher of *Nepenthes;* and so we may find that the *Stigmaria* is no less a fern from its tissues being modified in arrangement. A still better illustration is furnished by some of the natural order *Magnoliaceæ*, that have the woody tissue closely resembling *Coniferæ,* and the parasitical *Myzodendrons* of Cape Horn, whose wood is like that of the ferns in many respects. These are genera certainly departing from their immediate allies in these characters, but not therefore allied to the plants which in those particulars they resemble.

The symmetrical quincuncial arrangement of the scars has been considered by very many observers to be all but conclusive against the

theory of *Stigmaria* being a root. We know, however, very little of the roots of living plants, their importance in systematic botany being trifling. There is, however, no good cause for supposing that symmetry should not pervade the subterraneous as well as the superior organs of plants; and in the case of the roots of some *Palmæ* in common use, but of unknown origin, we have an arrangement of rootlets round a prostrate root (analogous to the root of *Stigmaria*), as symmetrical as in *Stigmaria* itself.

M. Goeppert has recognised, in the majority of those species of *Stigmaria* which are founded on variations in the form and disposition of the sexes, only one. That such a view is concurrent with the fact of the genus representing merely a root, is obvious; for such an organ cannot be expected to afford specific characters. M. Corda, on the contrary, has given the name of *Stigmaria ficoides* to the dissection of a plant which evidently bears no very close relationship to the characteristic fossil of our British under-clay, and which is, doubtless, the true *S. ficoides* of authors. M. Corda's *S. ficoides* is, on the other hand, possibly a stem, and not a root.

There are in the Museum of Practical Geology so many *Stigmaria* specimens, the majority having only the external characters preserved (though in not a few the internal tissues, and in some both, are admirably displayed), that I can confidently affirm, that specimens figured by Corda (Tab. XII.), do belong to the same genus, and probably species, as M. Brongniart's dissections in the *Archives*. In proof of this assertion I would adduce the figures and dissections of Plate 2, Bot. figs. 5—13, all having been made from the one specimen, fig. 4.

Explanation of Plates.

Plate 1, figs. 1 and 2. Two views of a specimen of *Stigmaria*, fossilized without compression, and showing the pits or cavities from which the rootlets emerge in an unmutilated condition. The bases of these rootlets are generally retained within the cavity. Specimen from Peel Quarry, Lancashire, above the white-coal seam,—Mr. Ormerod's cabinet. Fig. 3, specimen of a similarly preserved fossil, from the cabinet of Miss Jukes, of Birmingham.

Plate 2, fig. 1, rootlet of *Stigmaria ficoides*. Fig. 2, horizontal section of ditto, very highly magnified, showing at *a* the position of the vascular axis. Fig. 3, cellular tissue from ditto, more highly magnified. Fig. 4, portion of *Stigmaria ficoides*, showing the scars as they usually appear, and enclosing an axis from which the dissections 5—13 were taken. Fig. 5, horizontal section of axis in fig. 4, of natural size. Fig. 6, posterior ends (those towards axis) of the vascular tissue (*b*) forming the wood, divided by broad and narrow medul-

lary rays (*a*). Fig. 7, anterior (or circumferential) end of vascular axis; *a*, vessels passing through the medullary rays to the rootlets; *b*, vascular tissue of wood; *d*, bundles of small vessels towards circumference. Fig. 8, very highly magnified view of one of the narrow medullary rays (fig. 6 *c*), forming a bundle of tubes of less diameter than those forming the wood. Fig. 9, vertical section through the axis of fig. 5. Fig. !0, magnified portion of fig. 9, showing at *a* the longitudinal vessels of the wood; at *b*, the horizontal ones passing through the medullary rays. Fig. 11, another magnified portion from the circumference of the same; *a*, the longitudinal vessels displaced by the horizontal ones, *b*, which are fractured in the fossil, and pass upwards towards the rootlets at *b′*. Fig. 12, section of the axis (fig. 5) taken at right angles to the medullary rays. Fig. 13, very highly magnified portion of ditto, showing the longitudinal vessels of the wood, *a*, displaced by the horizontal ones, *b*, whose mouths are cut across, issuing through the medullary rays. Fig. 14, horizontal section of another axis, from a specimen marked externally as in fig. 4, and whose structure accords with that of figs. 5—13.

Remarks on the Structure and Affinities of some Lepidostrobi. By Dr. Hooker, F.R.S., &c., Botanist to the Geological Survey of the United Kingdom.

The numerous detached petrified cones which are scattered through the various strata of the coal formation, being obviously organs of fructification, and having therefore belonged to some of the arborescent plants whose remains they accompany, are objects of peculiar interest to the fossil-botanist and geologist. Such of them as are preserved in the nodules of iron-stone, or are otherwise mineralized without pressure, alone offer the means of ascertaining to what existing families of plants they are most nearly allied; for in those that are crushed flat in the shales the internal structure is wholly destroyed. Many of the better preserved specimens have been sliced, polished and examined with the greatest care; but this expensive operation has hitherto thrown little light upon the true nature of the objects thus investigated.

This is because the three following conditions for their complete illustration has never been displayed by one specimen, and the most important point—the nature of the organs of fructification—has hitherto wholly escaped observation in all. Every cone being an aggregation of organs of some kind, it becomes necessary to ascertain not only the arrangement of these organs, but the nature of the tissues composing them, and (even more essential) their contents, before satisfactory conclusions can be drawn as to their relationship to any of the vegetable remains they accompany, or to whatever existing order of plants they are allied:—

1. The arrangement of the individual organs of fructification, of which the cone is an aggregation, and the nature of the scales supporting them. These are characters sometimes displayed on the fracture of the specimen by ordinary means, though rarely, from the parts appearing to have suffered partial decay previous to or during petrifaction. The imbricating apices of the scales, which lie over one another like those of a pine-cone, are generally removed with the matrix wherein the fossil is imbedded, as is seen by contrasting plate 8, fig. 1, with fig. 3, in the former of which the apices of the scales have persisted, whilst in the latter they are uniformly broken away. The mutilated is the more usual state of the surface, for reasons which shall be afterwards detailed.

2. The tissues, or anatomical structure of the various organs composing the cone; viz., of the central axis, which is a continuation of the

stem of the plant;—of the scales, which, being inserted into the axis, support the individual male or female organs;—and of the latter themselves. These tissues can only be displayed by slicing fossils in the very best state of preservation, and in such as are changed into a more or less transparent mineral. Specimens of this description are exceedingly rare, and have not hitherto been described.

3. The two above considerations are secondary to the remaining one, the nature of the contents of the cones. There may be stamens or male organs,—ovaria, or female ones;—or lastly, capsules containing reproductive spores (which are peculiar to plants having no sexual system); for these three kinds of organs all occur arranged in the form of cones, undistinguishable from one another by any external marks. Up to the present time no carboniferous fossil cone has ever been known to supply this great desideratum, without which we can arrive at no exact conclusion as to whether these curious objects are clusters of flowers, or fruits, or are the spore-bearing organs of flowerless vegetables as mentioned above.

Sections of numerous fossil cones have been prepared for the Geological Survey, with the view of illustrating these several points. Many have hardly repaid the trouble and expense of slicing, whilst others, which from external characters had been considered the least profitable, have, on the contrary, turned out the most instructive. It is a fact, that neither the most experienced lapidaries, or collectors, nor the geologists, mineralogists or botanists, have been able to decide in the majority of cases by the external appearance of a fossil cone how its internal and microscopical tissues shall be preserved. As an instance, it may be mentioned, that the most beautiful of all the *Lepidostrobi* which I have seen (that figured at plate 8, fig. 1) is utterly worthless as a structural specimen. This circumstance, combined with the rarity and singularly elegant forms of these plants, must ever render their collection and investigation among the most attractive and curious branches of Fossil Botany.

The circumstances under which these structural specimens occur are not the least interesting points in their history. All are found in the seams or nodules of clay iron-stone, and are very highly mineralized, sometimes containing crystals of iron, and the cavities in their substance being filled with white carbonate of lime and magnesia. Those which are most complete always form the nuclei to nodules of clay iron-stone—such are those figured at plate 7 and plate 8, fig. 1; but in these the internal tissues are nearly obliterated. Others again, including all in which the spores are preserved, have occurred as broken frustules, *within* stems of *Lepidodendron elegans* and other species of that genus.

I have examined as many as thirty specimens of cylindrical truncheons

of *Lepidodendron*, each from two or three inches to a foot long and from two to five inches in diameter, from the Staffordshire coal-fields, all of them containing one or more fragments of *Lepidostrobi.** These *Lepidostrobi* are of various lengths, they run parallel to the stem in which they are enclosed, are of all ages, and in various stages of decomposition.

In one large stem, figured at plate 9, fig. 2, and plate 10, fig. 1, the remains of upwards of thirty *Lepidostrobi* are crowded together with broken-up portions of the bark and of other parts of the *Lepidodendron* itself. When they are solitary, which is very frequently the case, they resemble the vascular axis of the *Lepidodendron*, and are usually taken for such; but a very slight examination suffices to shew their true nature.

Usually the fragments of *Lepidostrobi* are not more than half an inch long, and very frequently are mere discs; so that though there is often the appearance of one several inches long, and traversing the whole length of the fragment of *Lepidodendron*, it will generally be found that this is owing to two being placed each at an extremity of the truncheon, and opposite to one another. That all were exceedingly brittle cannot be doubted, for no modern cone of any natural order could be broken up into the shallow discs which many of these fossils present. This brittleness of *Lepidostrobi*, combined with that of *Lepidodendron*, is in consonance with the remark I have elsewhere made, that the tribes of plants that were converted into coal, were all of a singularly compressible and succulent texture.

It is difficult to account for the presence of these fragments of *Lepidostrobi*, and especially of so many in one *Lepidodendron* stem as are shewn in plate 10, fig. 1. We can but conjecture that the trunks of the latter were erect stumps whose interior was hollowed out by decay, that these stumps were covered with water, charged, so to speak, with myriads of broken fragments of *Lepidostrobi* and other vegetable matter, which were washed by the fluid into the stumps. These points, however, demand a separate consideration, and will be better understood by a reference to the figures in plate 9, and those of transverse sections of the same fossils in plate 10, bearing in mind that the *Lepidodendron* stems or stumps are stuffed throughout with fragments similar to those figured in plate 10.

1. The stumps appear to have been rooted and erect, and to have received the cone fragments into their cavity, as fern fronds find their way into the axis of *Sigillariæ*. Were the stumps mere prostrate por-

* There is in Lord Stamford's Museum, at Enville Hall, a very valuable collection of coal fossils, made by Mr. Beckett, of Wolverhampton: amongst them is a cylindrical specimen of *Lepidodendron*, containing three species of shells labelled *Unio aquilinus*, *Modiola carinata*, and *Mytilus triangularis*.

tions of stems, it is evident that cones would have lain horizontally in them, and that no washing or drifting could have induced the fragments of these cones to lie with their axis parallel to them, or could have introduced so many into one trunk ; and the latter would certainly have been materially compressed had they received on one side the pressure of the superincumbent shales.

2. The stumps must have been submerged, and the fragments quietly deposited from the water. Had the cones fallen into the stumps from an overhanging forest, they would have alighted in all manner of irregular positions, and in some cases overlain one another, which I have never seen to be the case.

3. The deposit appears to have been effected by the gradual subsidence of the water, and not by a sudden rush or current. This again is proved by the non-interference of the cones, and their uniformly vertical position with respect to the *Lepidodendron*, a fact to which I cannot too strongly call attention. It might be expected, that however tranquilly they were deposited, some irregularity should occur in their arrangement, and such may yet be observed, though in the various sections I have had the advantage of seeing made under my own direction none has been noticed.

It is hard to account for the accession of so large a volume of water as should submerge these stumps and deposit the fragments, and yet exhibit no evidence of drifting in its course. The sudden fall of a tropical torrent of rain, on a *Lepidodendron* forest, in which were hollow stumps of these trees, must at once suggest itself. This would both carry down the *Lepidostrobi* from the trees and float up the fragments on the ground, depositing them together in the stumps. Another effect of such a fall would be to break down some of the older trees, whose decaying stumps would be prepared to enclose other *Lepidostrobi* on the precipitation of the next similar torrent.

It may be asked, why the same agent that produced all the deposits over the coal, should not both have filled the trees and enveloped the whole in silt. To this I would answer, that the action does not appear to have been sufficiently violent, that the beds of iron-stone nodules, or continuous seams of clay iron-stone in which this kind of fossil occurs, bear no evidence of having contained the remains of a luxuriant forest vegetation, similar to what the coal-shales present; and that the repetition of such phenomena as I have assumed to have filled the stumps with fragments, is very likely to have impregnated the iron-charged mud with carbonized matter in a state of the most subtle comminution, which is the character of the carboniferous iron-stone wherein these specimens are imbedded.

The extreme fragility of the *Lepidostrobi*, displayed by these speci-

mens, is to me very satisfactory, as the *Lepidodendrons*, of which they are the fruit, no doubt partook of this character, which is eminently favourable to a rapid decomposition and intimate union with the silt or mud which is the basis of the clay iron-stone in the one case, and the formation of a homogeneous bed of vegetable matter, such as the coal presents, in another. The extraordinary abundance of the fragments, too, indicates a most vigorous vegetation, for they must indeed have been profusely scattered to be deposited in such numbers within narrow cylinders, into which no current appears to have been directed.

It is worthy of remark, that no fern leaves are contained in any of these *Lepidodendron* stems; and their absence is the more singular, from their being commonly deposited, along with branches of *Calamites*, &c., in the erect stumps of *Sigillaria* resting on the coal-shales. This is no doubt connected with the well-known fact of the *Sigillaria* stumps being filled with sandstone, or the same materials as those composing the stratum above the shales they root into; whilst the fossil *Lepidodendron* of the clay iron-stone seams is of the same mineral as that wherein it is imbedded. Were the fragments of *Lepidostrobi* washed into their enclosing stumps by any current, that agent would in all probability have transported the remains of other plants to the same spot.

The perfect preservation in which these fragments occur must be attributed to the protection afforded them by the surrounding *Lepidodendron* bark. That the circumference of the latter has been subjected to pressure may be inferred from the flattening of the prominences to which the leaves were attached. This pressure was moreover very considerable, as may be proved by comparing the evenness of their surface with that of a piece of *Lepidodendron* bark fossilized without pressure and embedded within the stem along with the *Lepidostrobi* (plate 10, fig. 1). From this it may be seen that the scars of the surface occupied the faces of diamond-shaped projections, elevated a full $\frac{1}{6}$ of an inch and more above the surface of the stem, and that they were separated from one another by deep grooves which dilate inwards: in other words, the prominences are broader at their bases than on their surface.

To illustrate this beautiful and hitherto unobserved character of *Lepidodendron* bark, I have figured (plate 8, fig. 12), a unique specimen preserved in a very hard and tough iron-stone, for the loan of which the Geological Survey is indebted to Mr. Cooper, of Bilston. It is not known to what favourable combination of circumstances this fossil owes its rare and perfect state of preservation: it is the only specimen of the kind that I have seen, and, like the *Stigmaria* fragments figured at plate 1, it throws a new light upon the subject it illustrates. In this the surface that bore each leaf projects a full $\frac{1}{6}$ of an inch beyond that of the stem itself, and is perforated by a tubular cavity through

which the bundle of vessels that diverged from the vascular axis of the stem to the leaf passed out.

The uniformity of the surface of the *Lepidodendrons* figured at plate 8, is an argument for their having been erect when fossilized, and proves that the deposition of the *Lepidostrobi*, &c., into their interior was effected by, comparatively speaking, tranquil waters. Had the specimens been drifted, or exposed to the action of a rushing current, on one side or the other, they must have shown it by the obliteration of some of the scars, or probably the adherence of other fossils to their surface. Again, had the stems been prostrate, the same pressure that flattened the once prominent scars, would have compressed the cylinder also.

The above are the only observations I have to offer upon these specimens relatively to the formation wherein they were found, and the circumstances under which they appear to have been fossilized: the remainder refer to the botanical characters of the *Lepidostrobi* themselves, to the strong evidence these specimens contain of their belonging to the *Lepidodendrons* that enclose them, and to the proofs which the discovery of their spores and tissues yield of both being allied to the existing genus *Lycopodium*.

*Description of the Specimens.**

Plate 3. This and the following plate represent the fragment of a *Lepidodendron*, enclosing in its once hollowed axis several *Lepidostrobi*. The specimen was received through Mr. Jukes from Mr. Lowe, of Wolverhampton, who obtained it from the iron-stone seams in the neighbourhood of that town.

Fig. 1. External surface of the fossil, displaying the markings of the *Lepidodendron Harcourtii* of the natural size.

Fig. 2. Lower surface of the same, showing the fractured surfaces of a mature and very young *Lepidostrobus*.

* It is with regret that I find myself obliged to introduce here a detailed description of the specimens, of which the plates are faithful and beautiful copies; but to understand all the points of structure in these interesting fossils, it is essential that the reader be familiar with these. Perhaps there is no more tedious and perplexing task than that of restoring a fossil plant of the coal formation. No solitary specimen among the many prepared at great cost and labour by the Geological Survey has fully illustrated any of the various points now, I hope satisfactorily, cleared up. The restoration of a *Lepidostrobus* is effected by taking a cell here and a cell there out of many individuals, and the tubes of vascular tissue, spores, &c., from various other cones. The adaptation of these to one another, and arrangement of the whole, are, after all, a mental operation. It is, however, imperative on the restorer to give every feature he has availed himself of in detail; that the experienced observer may pronounce on the justice of his views, or point out the error of his judgment; and that the tyro may know how to proceed in following similar investigations.

Fig. 3. Magnified view of the four somewhat distorted scars on the surface of fig. 1.

Plate 4, Fig. 1. Opposite surface of the fossil from that figured in Plate 3, showing a large *Lepidostrobus*, whose base rests on the curved crest of what was perhaps a branch supporting the cone.

Fig. 2. Upper fractured surface of the fossil, showing the large mature cone *a*, and a somewhat smaller one lying parallel to it. The point, where lines, drawn from the daggers *a* and *b* would intersect, indicates the position of the very perfect apex of one of the sporangia which are arranged round the axis.

Fig. 3 represents four scales (two restored) from the surface of the cone *a*.

Fig. 4. Sporangia chipped off the cone *a*.

Fig. 5. Magnified view of a sporangium, restored according to the appearances presented by the apex of the sporangium of the smaller cone seen in fig. 2.

Plate 5. Vertical sections from the *Lepidostrobus* figured in Plates 3 and 4, taken through the axes of the cones.

Fig. 1. A vertical section taken from the cone, Plate 4, figs. 1 and 2 *a*, in the direction of the dagger *a*, cutting through the axis and portions of several sporangia on either side. The axis retains hardly a trace of organization beyond a little cellular tissue on its outer margin. There are no remains of the bases of the scales supporting the sporangia, which were once inserted into the axis. The sporangia are large and long, occupying nearly the whole semidiameter of the cone, and slightly curved, with the convexity upwards, as shown at Plate 4, fig. 4. Their walls are of extreme tenuity, formed of a single row of parallel cells (seen at Plate 6, fig. 4 *c* and 10), and they contain the spores.

Fig. 2 is a magnified view of some of the tissues of the walls of the sporangia *b*, and the vascular tissue of the scales *a*, the latter composed of tubular vessels which communicate from the apices of the scales and the axis of the cone.

Fig. 3 shows the dorsal portion (that nearest the axis) of a sporangium, whose position is indicated by the intersection of lines drawn from the daggers *a b*, of fig. 1. Towards the back of this are seen numerous spores from the opaque mass which fills the greater part of the sporangium.

Fig. 4 is a portion of the same, so magnified as to define the spores.

Fig. 5. Dorsal portions of two other sporangia, indicated in fig. 1 by the daggers *b c*, between the bases of which some escaped spores are enclosed in a transparent mineral *x*.

Fig. 6. The portion marked *x* in fig. 5, magnified equally with fig. 4.

Fig. 7. A group of spores from fig. 5, very highly magnified, exhibiting their characteristic trisection by opaque lines.

Fig. 8. A smaller group of more advanced spores from fig. 3, still more highly magnified.

Fig. 9. Individual spores selected from figs. 4 and 6. They are generally tetrahedral bodies, divided into three by broad transparent spaces. The youngest, *a*, *b*, *c*, are immature, and present spurious projections at their three angles, which spines are continuous with the transparent spaces and acute, deformed by prolongations of the contiguous apices of the three sporules comprising the spore. Letter *d* indicates a more mature spore, with the spines very nearly obliterated. At letter *e* is a still more matured spore, whose angles are rounded, and in which the transparent spaces are broader, indicating that the spore has all but broken up into three sporules.

Fig. 10. A vertical section, of the natural size, of a portion of the cone, Plate 4, fig. 2 *a*. In this the tissues of the axis are preserved. This axis is hollow in the centre from the obliteration of the once cellular (?) tissue filling it.

Fig. 11. A semi-diameter of the axis of fig. 10, showing at *a* the tubes of vascular tissue, which once formed a continuous zone round the pith; *b*, the system of vascular tissue exterior to the former, which gives off the bundles *c* to the scales of the cone. The arrangement of these tissues will be best observed by referring to the wood-cut of these parts in *Lepidodendron*, at p. 436 of this volume.

Fig. 12. Tubes of the perpendicular vascular tissues *a*, of fig. 11. These are marked with horizontal rings, sometimes free, at others anastomosing at various points.

Fig. 13. Slender tubes *b*, of the vascular system, *c* of fig. 11, supplying the scales. They are surrounded by cellular tissue *d*, formed of elongated utriculi. The tubes are much more delicate and slender than those of the other system of vessels.

Plate 6. Horizontal sections of the cones, Plates 3 and 4.

Fig. 1. Slice of the mature, *a*, and immature, *b*, cones, seen in Plate 3, fig. 2.

Fig. 2. A portion of the coaly bark close to the surface of the *Lepidodendron*, showing its cellular tissue.

Fig. 3. A highly magnified portion of the cone, fig. 1 *a*, showing a section of the apex of one scale, with several others imbricating over it.

Fig. 4. Still more highly magnified view of a portion of a similar scale, edged by the walls of a sporangium *c*. The scale is chiefly formed of cellular tissue, enclosing in its centre a mass of vascular tissue *a*, which turns up to the ascending apex of the scale at *b*.

Fig. 5. Vessels seen at fig. 4 *b*, as they ascend towards the apices of the scale, fig. 4, and are consequently cut across by the lapidary. These vessels are figured at Plate 5, fig. 2 *a*, and Plate 8, figs. 6, 7, and 11 *a*.

Figs. 6 and 7. Portions of the crystallized cellular tissue of the axis of the cone, fig. 1 *a*, in which the circular holes, *a*, indicate the position of the vascular bundles supplying the scales, which are vertically sliced in Plate 5, fig. 11 *c*.

Figs. 8 and 9. Magnified portions of the small mutilated cone, fig. 1 *b*, showing the positions of the spores which are retained in the young cone, but of which there are no traces in the large cone, fig. 1 *a*.

Fig. 10. A portion of the walls of a sporangium, cut obliquely by a horizontal line, so that at one portion, *a*, the lateral cells are divided according to their long axis, whilst at the other, *b*, the cells forming the floor, are cut across their short axis.

Fig. 11. Ripe spores from the small cone, fig. 1 *b*, one of them, *a*, divided into four cohering sporules.

Fig. 12. Other spores more advanced, *a*, ready to separate; *b*, the sporules detached from one another; 3, a sporule detached wholly, probably in a state once ready for germination.

Fig. 13. Horizontal section of another part of the cone figured at Plate 3, fig. 2. This is crushed on one side, but tolerably perfect on the other, and there displaying some ripe sporangia, with a few spores in each.

Fig. 14. Magnified view of the axis.

Fig. 15, Portions of three sporangia, with a few spores scattered at their bases.

Fig. 16. More highly magnified view of portions of these sporangia and their contained spores.

Fig. 17. Spores from the same, in various stages of development.

Fig. 18. Some spores very highly magnified, all young, and the component sporules not only separated, but bounded by a transparent space, and the whole surrounded by a jagged border, probably the effect of crystallization.

Plate 7, illustrates a beautiful specimen of *Lepidostrobus ornatus*, preserved in a nodule of iron-stone. The specimen is from Glamorganshire, is preserved in the Bristol Museum, and liberally placed at the service of the Survey, not only for illustration, but for slicing, by Mr. Stutchbury, with the approbation of the directors of that institution.

Fig. 1. *Lepidostrobus ornatus*, Lindl. and Hutt., of the natural size.

Fig. 2. Vertical slice, taken through the axis, showing that the apex is undeveloped, and the cones hence hardly mature.

Fig. 3. Vertical slice of lowest scales and sporangia.

Fig. 4. Horizontal slice of semi-diameter of cone through the middle.

Fig. 5. Vascular tissue of the scales supporting the sporangia.

Fig. 6. Cellular tissue of ditto, restored from cells in various scales.

Fig. 7. Cellular tissue comprising the walls of one of the sporangia.

Fig. 8. Ideal representation of a horizontal section of a restored cone, showing eight scales, radiating round, and inserted into the axis, each bearing a sporangium.

Fig. 9. Ideal representation of a vertical section of two sporangia and their supporting scales, the latter traversed by vascular tissue.

Plate 8, Fig. 1. Fragment of a cone of *Lepidostrobus ornatus*, in which the apices of the scales are admirably preserved. Specimen from Mr. Beckett of Wolverhampton.

Fig. 2. Apices of scales of ditto magnified.

Fig. 3. Upper extremity of a *Lepidostrobus* from which the apices of the scales are removed. In the collection of Miss Jukes, of Birmingham.

Fig. 4. Vertical section of the same, showing that the axis has fallen away, as also the apices of the scales.

Fig. 5. Magnified view of the fractured terminations of the scales, each with a prominence in its hollow, which is the projecting bundle of vascular tissue, shown at fig. 11 *a*.

Fig. 6. Portion from another specimen of *L. ornatus*, showing the union of the walls of the sporangium *c*, with the scale *d*, at the point *b*; *c* is the vascular axis of the scale.

Fig. 7. More highly magnified portions of fig. 6, showing the disposition of the cells at the junction of the walls of the sporangium, *c*, with the scale, *d*. At letter *a* is seen the vascular tissue of the latter, and at *e* an escaped spore.

Fig. 8. Vertical slice of another *Lepidostrobus ornatus*.

Fig. 9. Mutilated apex of ditto, with spores escaped and mineralized in a transparent medium.

Fig. 10. Spores from the same, some of them broken up into their component sporules.

Fig. 11. Restored view of axis of cone, *x*, with two supporting scales, *b*, transversed by vascular tissue, *a*, the lower one bearing a sporangium, *s*, with its contained spores. The apices of the scales are represented broken off, as at figs. 3, 4, and 5, but restored by dotted lines, as in figs. 1 and 2.

Fig. 12. Fragment of *Lepidodendron elegans*, preserved in iron-stone, without any material compression, and hence showing the surface scars as prominent bodies. It is in the collection of Mr. Cooper, of Bilston, who procured it near that town.

Plate 9, Fig. 1. Specimen of *Lepidodendron elegans* in the cabinet of

Mr. Cooper, of Bilston, containing three tolerably perfect *Lepidostrobi*, and the remains of very many others, all vertically disposed in its axis —of the natural size.

Fig. 2. A much larger specimen of the same fossil, *reduced one-third*, from Mr. Beckett, of Wolverhampton, containing more or less perfect fragments of upwards of thirty cones of *Lepidostrobus ornatus*, besides other vegetable matter.

Plate 10, Fig. 1. A horizontal section of the fossil represented in Plate 9, fig. 1, showing the arrangement of the *Lepidostrobi* in its axis.

Fig. 2. Magnified view of semi-diameter of a very young cone, whose position in Fig. 1, is indicated by the two arrows. It is also probably the upper end of a cone, and contains sporangia full of spores.

Fig. 3. Spores and sporules from the same, of various ages and sizes, all rather mutilated.

Figs. 5 and 6. Fragments of vessels forming the vascular axis of the scales, in the same specimen.

Fig. 7. Horizontal view of Plate 9, Fig. 2, *of the natural size*, showing the numerous fragments of cones, and a curved portion of the bark of *Lepidodendron*, the position of which is indicated by the four arrows.

If the several points thus obtained be, so far as they refer to the structure of the cones, singled out and arranged, it will be seen that in the aggregate they afford a very complete knowledge of every part of the genus *Lepidostrobus*, which may be thus described :—

Cone variable in length, cylindrical, obtuse at both ends, gradually tapering towards the apex, formed of a perpendicular axis, around which are arranged horizontal scales, each bearing a sporangium, or hollow vessel filled with spores.

Axis cylindrical, consisting chiefly of cellular tissue, traversed by tubular vessels, which compose the vascular tissue. Vascular tissue of wood, Plate 5, fig. 11 *a*, forming a continuous ring enclosing the pith of the axis, composed of long hexagonal tubes, whose sides are marked with free or anastomosing transverse lines. Around this vascular tissue of wood are arranged bundles of smaller and more delicate tubes, Plate 5, fig. 11 *b*, which radiate outward to the basin of the scales.

Scales horizontal, 8-16 in a whorl, composed of two parts. Firstly, a slender pedicel, inserted into the axis and supporting the sporangium, Plate 8, fig. 11 *b*, formed of vascular tissue, through the axis of which runs the bundle of vascular tissue, fig. 11 *a*. Secondly, a broad dilated apex, at right angles to the pedicel, fig. 11 *c*, produced upwards into a triangular acute point, fig. 2, and downwards into a blunt lobe, fig. 11 *e*, also traversed throughout its length by a continuation of the vascular bundle of the pedicel. This dilated apex is formed of very loose cellular tissue laxer, especially towards the centre, which is generally

hollow; the anterior portion of this body is hence frequently removed, as seen at Plate 8, figs. 3 and 5, leaving a pitted surface to the cones.

Sporangia oblong, resting on the pedicel, and each attached by its lower face towards the apex of the latter by a small surface. Some, perhaps all, of these sporangia are furnished with ribs, Plate 4, fig. 5. Walls formed of a single layer of transversely elongated cells, Plate 6, figs. 4 and 10, and Plate 8, fig. 6 *a*. Mode of dehiscence or bursting to allow the escape of the spores unknown.

Spores consisting of three, or rarely four sporules, which are afterwards separated from one another, the immature produced at their angles into acute spines, the older suborbicular.

The two cones, from which the above general views have been deduced, are apparently from different species, and I shall therefore characterize them as such. Further, as they seem to have belonged to the fossil *Lepidodendron* enclosing them, I shall for the future notice them as really the fruit of that genus.

1. LEPIDODENDRON *elegans*. Cone slender, $\frac{3}{4}$ inch in diameter, 4-10 inches long, sporangia 8 in a whorl.

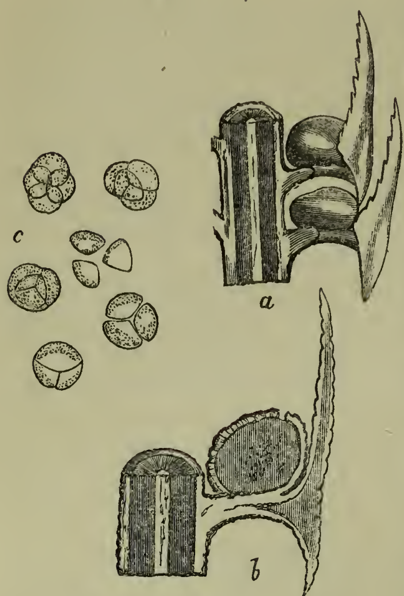
2. LEPIDODENDRON *Harcourtii?* Cone broad, $1\frac{1}{2}$ inch in diameter, sporangia about 16 in a whorl.

If, now, these cones be examined with reference to the known contemporaneous fossils which accompany them, it will appear impossible to deny their having the reproductive organs of *Lepidodendron*, not only from their association with the fragments of that genus, because the arrangement of the tissue in the axis of the cone entirely accords with that of the stem of *Lepidodendron;* just as we find, in modern cones of *Lycopodiaceæ* and *Coniferæ*, that the axis is a continuation of the branch which bears leaves, modified into organs adapted to support and protect the parts of fructification.

The most positive evidence that can be adduced of *Lepidostrobi* being a genus allied to *Lycopodium*, is afforded by the spores, the presence of which not only removes them from *Cycadeæ*, *Coniferæ*, or any other order of flowering plants, but directly refers them to the family of *Lycopodiaceæ* and *Coniferæ*. In both, the original spore divides into three or nearly four sporules, which are angular, and form the reproductive system of the plant. Not only do these groups coincide in the essential character of their spores, but, in many minor points, the strongest similarity exists between them. The arrangement of the scales is the same in both, and so are the scales themselves in general features, especially towards their dilated apices. The situation of the sporangia, too, is alike, and their attachment by a very narrow surface to the scale.

To illustrate this properly, the following illustrations (fig. 1), were prepared. That at Plate 8, fig. 11, should be compared with this wood-cut, where the only material difference between them is in the shape of the sporangium. The spores *c*, from *L. Selago*, should be compared with those of Plate 5, figs. 7, 8, 9; Plate 6, figs. 11 and 12; Plate 8, fig. 10; and Plate 10, fig. 3.

Fig. 1.



Previous to the investigations of M. Brongniart, the prevailing opinion with regard to these cones was, that they belonged to plants of the Pine tribe. Their great size and the presence of coniferous wood in the coal formation both favour this supposition.

It is, however, well known to the botanist, not only that cones are far from being peculiar to one natural order of plants, but that their extreme form is no indication, either of their contents, or of the affinities of the plants which produced them. Accordingly, we find that Dr. Lindley, the first English observer who published any extended views on the affinities of these plants, suggests the probability of their being referable either to *Coniferæ, Lycopodiaceæ,* or more probably still to *Cycadeæ.**

The scales, to whose arrangement the production of a cone is due, are in no essential respect different from those that occur on other parts of the plant. The doctrine of morphology teaches us, that the cone is nothing more than the leafy apex of a branch, whose leaves are modified in form, generally to the end that they shall perform the office of protecting organs to reproductive bodies; this is the case with the Pine cone, that of the *Lycopodium* or club-moss, and many other plants.

Cases are however not unfrequent, of what may be termed false cones, which have no relation to the reproductive organs of the plant. In some species, they are common, and are naturally produced, as in the well-known cone-bearing willow, and in the larch, which produces barren cones, unconnected in every way with those containing the seeds.

* Lindley and Hutton, Fossil Flora, t. 11, sub. *L. variabilis.*

The normal arrangement of the leaves of a plant is spiral around the branch: when the latter is very short, and the leaves also short and crowded, the whole branch becomes a cone; this is frequently seen on the apices of the branches of some plants, and is also artificially effected in others, by an injury to the branch, which prevents its elongation. In Tierra del Fuego there is a genus, several species of which have the branches punctured by an insect; the consequence is, that the wounded portion is arrested in its tendency to prolong, the sap is thrown into the leaves, which become broader and otherwise of different appearance from the usual form of leaf, and lap over one another, so as to produce a cone.

I have thus long dwelt upon the formation of spurious cones, because some of the so-called *Lepidostrobi* may be of this nature, — witness the *Lepidodendron oocephalum*, * of which it is impossible to say whether it be a *Lepidostrobus* or the apex of a branch crowded with short leaves.

The Fuegian plant mentioned above illustrates this subject, and a wood-cut of two species of the genus alluded to (*Pernettya*, allied to the "Heaths") is added. Both were collected at Cape Horn, where the plants were invariably thus coniferous in the diseased branches, while the healthy bore little bell-shaped flowers. Instances of this sort

Fig. 2.

are not very uncommon on individual species, but a general tendency in the development in question is sufficiently curious. Were the above figured plants to occur fossil, the probability is, that their cones would be regarded as the undoubted reproductive organs, and the plants themselves be provisionally referred to *Coniferæ;* in further evidence of which opinion the cold climate they inhabit might be adduced, and

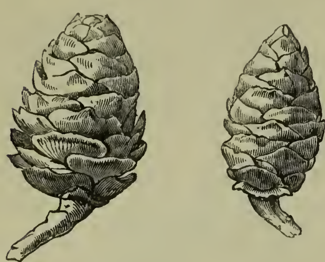
* Lindley and Hutton, Fossil Flora, v. iii., t. 206.

their general similarity to some really coniferous and totally different plants of Tasmania.

Cones, again, instead of being fruit-bearing organs, are frequently mere aggregations of male flowers. This is the case especially with the *Cycadeæ*, the cones of one species of which (*Dion edule* of Mexico) entirely resemble those of the truly coniferous genus *Araucaria*.

Proteaceæ are an order whose species abound in, and are almost confined to, Australia and South Africa, and whose (hermaphrodite) flowers are very frequently arranged in cones. Such cones would, if fossilized, and in the absence of any other evidence, be considered to have belonged to a coniferous plant. An illustration is added of such a Proteaceous cone, which, without examination, is calculated to deceive, even when recent, and if petrified, would assuredly be considered as belonging to a pine.

Fig. 3.



Lycopodiaceæ are the last (though not the only other) cone-bearing genera I shall mention; but as *Lepidostrobi* are to be directly compared with these, I omit any further mention of them here.

The size, form, and arrangement of their parts, together with the general disposition of previous observers to class the *Lepidostrobi* among *Coniferæ*, did not deceive M. Brongniart, who rightly conjectured them to belong to *Lycopodiaceæ*, and that too without any of that direct evidence, afforded by the specimen in the museum of the Geological Survey. Dr. Lindley, with his usual sagacity, had previously referred the cones to *Lepidodendron*, though ignorant of the nature of those tissues which also it has been our good fortune to obtain. In this opinion M. Brongniart concurs, and proceeds, in a review of the characters afforded by both *Lepidodendron* and *Lepidostrobus*, to cite his reasons for allying them to *Lycopodiaceæ*, rather than to *Coniferæ*, under which the authors of the Fossil Flora of Great Britain had arranged *Lepidodendron*.*

From the curious dichotomous ramification of the stem, M. Brong-

* The extreme perplexity of this subject may be gathered from the hesitation with which so excellent a botanist as Dr. Lindley always speaks of the affinities of *Lepidodendron*. In the introduction to the *Fossil Flora*, he regards it as *Lycopodiaceous*; under *Halonia gracilis* (Tab. 86), as probably *coniferous*; *Lepid. Harcourtii* (Tab. 89, 90) is pronounced intermediate between *Lycopod.* and *Coniferæ*; *Lep. selaginoides* (Tab. 113) is, he continues, rather *Coniferous* than *Lycopodiaceous*; and finally, under *Lep. elegans* (Tab. 118) and *Megaphyton approximatum* (Tab. 116), the *Lepidodendreæ* are definitively referred to *Coniferæ*.

niart inferred that *Lepidodendron* could not be a *Dicotyledonous* plant. The arrangement of its tissues clearly forbade its belonging to *Monocotyledones.* The cylindrical form of many of their (erroneously so called) cones was conclusive against their belonging to any coniferous plant, where these organs are always truly conical; whilst the form of these organs and the arrangement of their parts entirely tallied with *Lycopodiaceæ.*

In the details of M. Brongniart's description of the genus *Lepidostrobus*, there are some errors which, with the aid of more copious and perfect specimens, may now be corrected. It is satisfactory to know, that these rectifications throw light upon certain important points, in which it was supposed that this genus differed from any existing vegetable, presenting a most anomalous feature.

The first error then relates to the arrangement of the sporangia upon the supporting scales; they were imagined to be borne on the under-surface of the scales,* a misconception probably arising from mistaking the base for the apex of the cone, as shown at Fig. 2 *a* of Tab. 23.—(*Végétaux Fossile*, vol. ii.)

M. Brongniart further supposed the horizontal portion or pedicel of the scale, to be very broad, and to surround the base and two sides of the sporangium, which was thus enclosed between its own scale and axis, on all but the upper surface. In the specimens I have examined, on the contrary, the pedicel of the scale is exceedingly slender in comparison to its dilated apex, and of far less breadth than the sporangium, whose point of attachment to it is so small, that it can seldom be divided during slicing by the lapidary.

Lastly, M. Brongniart hesitates on pronouncing the *L. ornatus* of Lindley and Hutton to be *Lycopodiaceous.* If, however, as I suppose, the specimen, figured at Plate 7, is rightly referred to that plant, its affinities are undoubtedly with the other *Lepidostrobi.*

With regard to the number of species of *Lepidostrobus*, comprised in the Plates 3, 4, 7, 8, 9, 10, I do not recognize more than two, with any degree of certainty. One of them is that contained in the trunk of *Lepidodendron* (figured at Plates 3 and 4), and which is probably identical with the fragments figured in *Végétaux Fossile*, (vol. ii., t. 23, fig. 5 *a*, *b*). The second is the very long cylindrical cone, included within the trunk of *Lepidodendron elegans* (figured at Plate 8, fig. 1), and to which, in all probability, should be referred the cones Plates 7, 8, figs. 3 and 8, and Plate 10. This is allowing for great variation in the length of the cone, in one species, not more, however, than may be seen in very many of their existing allies the *Lycopodia* as the

* Végétaux Fossile, v. ii., p. 52.

accompanying wood-cut of the cones of the *L. Magellanicum* will show.

Fig. 4.

The internal structure, form of the sporangium, the length of the apices of the scales, and breadth of the cones, are very nearly alike in all the specimens. To this *L. ornatus* (Brongniart's Figs. 1, 2, and 4 of vol. ii., Tab. 23), should, possibly, be referred.

The beautiful little nut, of which a wood-cut is added,* is most probably a sporangium, belonging to this cone of *Lepidodendron elegans;* though differing in shape, its sculpturing corresponds with that of sporangium, removed and restored from *Lepidostrobus*, Plate 4, fig. 5.

The young state of this species is the very elegant specimen contained in a nodule of clay-iron-stone, figured at Plate 7. Besides the more conical and shorter form of the cones, they are distinctly attenuated to the apex, as if hardly matured. The apices of the scales, too, do not appear to be produced downwards to the degree of those of the former species.

Fig. 5.

* From the collection of John Gray, Esq., of Dudley. It is fossilized in a nodule of iron pyrites.

On the ASTERIADÆ *found fossil in British Strata.* By EDWARD FORBES, Esq., F.R.S., Professor of Botany in King's College, London: Palæontologist to the Geological Survey of the United Kingdom.

DURING the course of the researches of the Geological Survey many remarkable fossil Radiata have been brought to light, some of which involve important considerations both geological and zoological. Of such of those as are most intimately connected with the older palæozoic rocks, I purpose to give a full account in this volume, more especially of the Asteriadæ and Cystideæ; tribes, which, so far as Britain is concerned, have hitherto attracted but little attention in the fossil state.

Not long ago, and until within a very few years past, it was supposed that true starfishes were animals whose appearance in the earth's seas dated from the Oolitic period at earliest. The few fossil species on record had been observed in secondary formations. Their relations with existing forms were uninvestigated, and, indeed, the scientific study of the latter had scarcely commenced. Within the last ten years, however, the attention of zoologists has been strongly directed towards the Echinodermata, and numerous memoirs, both physiological and systematic, have been published upon this interesting order of Radiata.

The structure, habits, and sources of character, generic and specific, of the existing starfishes having been lately extensively investigated, and a good basis for comparison attained, it is time to inquire into the history and generic relations of their fossil allies; the more so, as notices of not a few species are scattered through geological memoirs. Numerous undescribed species exist in collections, and good specimens of many recorded forms, of which slight fragments only have been described or figured. The inquiry is one of great interest, for through it we may hope to attain a knowledge of the earliest features of this important section of radiated animals; to ascertain whether the order as a whole has undergone material changes during its progression in time; whether the earlier forms were rudimentary or equal in perfection of organization with those now living; and whether we can obtain information respecting the conditions of climate or depth under which they lived in the several geological epochs. The last point is especially important, for as we know that the forms of existing Echinodermata have a distribution highly characteristic of regions and conditions in space, we may hope to find an analogical distribution of the fossil species in time.

Whilst a great part of the extinct Zoophyta closely approximate existing types, a large proportion even of the palæozoic species bearing no small resemblance to existing forms, the majority of the higher Radiata which have been preserved exhibit generic, and even sectional differences, separating them from their living allies. These differences are especially conspicuous among the Echinidæ and Crinoideæ. The older genera, and even tribes of the last-named group, became extinct before the epoch of the secondary rocks commenced, and in existing seas there are but few members of the crinoidal type. The group is essentially *chronomorphic*. The Echinidæ are doubtfully indicated as yet among palæozoic forms; but those of secondary formations frequently belong to genera, which have become extinct, and the development of which had an evident relation to points in time, for we find groups of species, presenting peculiar combinations of characters, limited entirely to a few consecutive formations. This centralization of a number of generic types in time among the Echinidæ, whilst the members of others range indifferently through vast epochs, is exactly analogous to the present distribution of sea-urchins, many of the genera of which are confined to limited zoological provinces, whilst the members of others are distributed all over the world.

The knowledge of these facts, and an erroneous and too hasty interpretation of them, led palæontologists to believe that the distribution of the starfishes in time was very limited, and had relation only to recent epochs. They were supposed to have been entirely absent during the Palæozoic epoch—an absence which, if true, would have formed one among the many remarkable negative characters which it apparently presents; but which, it seems to me, have been laid far too much stress upon, when we consider the slight acquaintance we have as yet with comparative geology. But a small portion of the earth's surface has as yet been examined with that minuteness which the palæontologist should require before he infers sweeping conclusions from negative facts. As well might the zoologist or botanist, having thoroughly explored one province, or even a connected group of provinces of distribution, draw from his researches general conclusions respecting the presence or absence of like beings with those which he has examined on other parts of the earth's surface, before they had been explored by competent persons. If many distant points be thoroughly examined, we may hope to come to tolerably correct inferences respecting the phenomena of life in the interspaces; and this is as true in time-investigations as in space-investigations: but in geology, until lately, our knowledge of the fossil faunas and floras of distant regions has been and indeed is still extremely limited, for the parts of the world best examined, viz., Europe and North America, have evidently, in a natural

history point of view, been portions of one province only—vast no doubt, but not vaster than some existing provinces of distribution recognized by those naturalists who have studied that important subject. Yet, this not having been borne in mind, speculations, presented as inferences from extensive series of facts, respecting the universal diffusion of species during the older epochs of the world's history ; the evidence they afforded of an universal climate ; the progression of organization in time ; the development of higher forms from lower ; the absence of great classes of organized beings ; and the causes of that absence dependent on the existence of peculiar atmospheric or terrestrial conditions, have been rife in geology : and, though probably partially true, yet as the logical process by which many of them were arrrived at is not quite clear, whilst the premises were often evidently insufficient, have led many able men, unacquainted with the certainties of our science, too hastily to regard geology as in great part a philosophical romance.

When we consider the enormous lapse of time which has rolled away since the earlier formations were deposited ; the changes which have taken place on the earth's surface during the interval ; the wear and tear which the hardest rocks must have undergone during their upheavals and depressions ; the little that is preserved to us of sea-beds which have been extensively exposed during comparatively recent times, the wonder is, not that we can find no traces of the former existence of numerous tribes of creatures, members of which now live upon our earth and its seas, but that so many types of forms, simulating existing organisms, should be preserved at all as evidences of the most ancient past. It is from positive and not from negative evidences, then, that the palæontologist should draw his conclusions ; unless when well-established laws, arrived at by naturalists from the careful study of the full and unmutilated chapter of the present, have evidently so strong a relationship of analogy with the phenomena of the past as to warrant their safe application.

Organic remains make their first appearance in British strata abundantly and in considerable variety about the parallel of the Bala Limestone and sandstones and shales associated with it. Much below that geological horizon fossils occur, the oldest known forms appearing to be *Lingulæ*, members of a genus of brachiopodous molluscs, still represented by species which do not vary much in form from their most ancient allies and predecessors. But before the deposition of the Bala rocks, the evidences of life within our own area are comparatively scant. In America corresponding palæozoic phenomena have been described.

The first traces of the appearance of Asteriadæ occur in rocks of the Bala series, or even lower in the geological scale. They were first noticed by Professor Sedgwick, who found them in beds of corresponding

age in Cumberland, where they were also observed by Mr. Daniel Sharpe. The researches of the Geological Survey have brought to light similar fossils in the Bala rocks, near Bala, and in the ashy slates at Drumcannon, near Waterford, where they were found by Captain James. These latter beds probably correspond in age with the former. It is very remarkable that forms of starfishes strikingly similar have been discovered in the Lower Silurian strata of the United States.

The Cumberland, Welsh, and Irish starfishes all belong to one genus. After a very careful examination of all the specimens I have been able to procure (and, through the kindness of Professor Sedgwick and Mr. D. Sharpe, every facility has been afforded), I am induced to refer them to the existing genus *Uraster* (*Asteracanthion* of Müller and Troschel), members of which are at the present day the most abundant starfishes in the British seas and throughout the North Atlantic. The general aspect of the palæozoic starfishes must have been strikingly similar to that of the *Urasteriæ* now living. Indeed, impressions taken from the latter in clay would so closely resemble those which we find in ancient rocks, that the critical eye of a naturalist would be required for the definition of their specific distinctness. Nor does this arise through the obscurity or imperfections of such impressions, for the external characters, so far as contour and sculpture of surface, and even many points of structure, are very completely indicated in them, rude as they may seem.

As yet, with the exception of the instances already referred to, only one other instance of the discovery of a palæozoic asteriad has come to my knowledge, namely, that of a well-preserved species, apparently also belonging to the genus *Uraster*, by M. Thorent, in the "Terrains anthraxiferes" of the department of l'Aisne. It is probable, however, that the progress of research will bring many more to light. In the older secondary strata not a few have been found, both in Britain and abroad. A doubtful form (*Asterias obtusa*) has been figured by Goldfuss from the Muschelkalk, who has also made known a true *Asterias* or *Astropecten* from the lias of Wurtemberg. Several species of *Astropecten* have been observed in the oolites of Yorkshire, and similar forms in corresponding beds in Germany, where Urasteriæ have also been found. A single example of a fossil *Luidia* has been made known from the marlstone of Yorkshire, and a *Goniaster* from oolitic beds in Germany. In the upper secondary (cretaceous rocks), numerous fossil starfishes have occurred, especially of the genus *Goniaster*. Representatives of *Oreaster, Astropecten*, *Asterina*, and *Arthraster* (n. g.), are also present in the cretaceous series. The few older tertiary starfishes with which we are acquainted belong to the genus *Astropecten*. Arguing from the analogy of their associates, there can be no question that starfishes were abundant in the tertiary seas. Yet how very rare

are the traces of their existence! In the later tertiary strata, the only evidence as yet procured of their presence during the deposition of those beds consists in a few minute fragmentary ossicula of *Urasteriæ*. Yet when we consider the gregarious habits of those starfishes, especially of the species to which the ossicula preserved in all probability belonged, it is very wonderful to mark the almost total disappearance of their exuviæ; and the fact should serve as a caution to those who would unhesitatingly infer the absence of a tribe of organized beings, especially of such as present few facilities for preservation, from the absence of their fossil remains. Even now, when dredging, we very rarely bring up any remains of dead starfishes, whilst the living animals are not only present in the locality explored, but often so abundant as to fill the bag of the dredge, to the exclusion of all other creatures.

Instead of confining this paper to an account of the palæozoic starfishes only, I have thought it desirable to embody in it a synopsis of all our British fossil species, and a notice of all foreign ones which which I am acquainted. This is the more necessary, as no connected account of the fossil Asteriadæ exists, and as the geologist has no text at present by which he may determine the species in his collection. This I could not have done but for the liberality of Mr. Dixon, of Worthing, in whose forthcoming work on the geology, &c., of Sussex, admirable figures are engraved of all the British cretaceous fossil starfishes, the original specimens of which have been submitted for my examination and description. In the course of this inquiry, I have, through the kindness of their possessors, examined the rich collections of Mr. Bowerbank and Mr. Toulmin Smith, and not a few fine specimens from the collections of the Marquis of Northampton, the Earl of Enniskillen, Sir Philip Egerton, and Mr. Stokes. I have especially to thank the Marchioness of Hastings for her kindness in entrusting me with the examination and description of a very interesting new marlstone form, one of many in her valuable cabinet. Through Mr. Charlesworth, and my colleague, Mr. John Phillips, I have also been enabled to complete our knowledge of the oolitic starfishes.

Most of the fossil starfishes described or noticed in geological works are given with the prefix *Asterias*, their describers contenting themselves with referring them to the old Linnæan genus, which has now assumed the rank of an order of Echinodermata. Agassiz, ever active and in advance, when, in his "Prodrome d'une Monographie des Radiares,"* he endeavoured to marshal existing starfishes into scientific order, (previously meritoriously attempted with less success by Nardo)† endeavoured to reduce such fossil forms as were then upon record into the same ranks.

* Mem. Soc. Sc. Nat. Neuchatel, vol. i. 1835. † De Asteriis in Oken's Isis for 1834.

The invaluable memoirs of Müller and Troschel,* and their great work on the starfishes, omitted the consideration of the fossil species, a catalogue of which was published by F. Dujardin, in the third volume of the second edition of Lamarck's "Animaux sans Vertebres," in 1840, but without subdivision of the species into genera. In Mr. J. E. Gray's "Synopsis of the Genera and Species of Starfish,"† reference is made to several British fossil species, and a genus (*Comptonia*) constructed for a greensand form. Professor Pictet, in his very useful "Manuel de Paleontologie," has followed Agassiz in his enumeration of the fossil species under various genera.

In the following synopsis, I have endeavoured to arrange all the fossil species under the genera to which they appear to belong. The palæozoic forms I have described as fully as the specimens will admit. Of all the others I have given diagnoses, or, where the materials were not sufficient, brief notices. Fuller descriptions of the British cretaceous species and admirable figures will be found in Mr. Dixon's work already referred to. Plates of the new palæozoic, oolitic, and tertiary forms will be issued by the Geological Survey, and are now in the engraver's hands. The lists of species are prefaced by notices of the characters of the genera to which they belong, especially such as are recognisable in fossil examples.

URASTER.

Asteracanthion, Müller and Troschel. *Asterias*, Gray.

The commonest starfishes in the British seas are members of this genus, distinguished from all others by the presence of four rows of tentacula or suckers in each avenue beneath the long more or less cylindrical arms. Although members of this genus are found in all parts of the globe, their abundance and predominance is certainly characteristic of the approach to the arctic or antartic regions. In warm climates they are the exception ; in cold, the rule. The reverse is the case in some other equally diffused genera, especially in the genus *Goniaster*. It is very remarkable, then, that all the true starfishes, hitherto discovered in a fossil state in the sedimentary deposits of the palæozoic oceans, appear to belong to this genus *Uraster*, whilst the majority of the cretaceous species belong either to *Goniaster* or to genera still more distinctly tropical in character.

All the Urasters have cylindrical and deeply cleft arms, the skeletons of which are composed of small irregular compressed ossicula, articulated with each other in a reticulated fashion. The disk is similarly composed, and is furnished with a minute vent. Both disk and arms are studded

* 'Uber die Gattungen der Asteriden,' in Wiegmann's Archiv fur Naturgeschichte for 1840, and 'System der Asteriden,' 1842.

† 'Annals of Natural History,' vol. vi. 1841.

with numerous short conical spines, either scattered singly, or grouped in a tuft-like fashion, and on the arms, whether single or fasciculate, arranged more or less distinctly in longitudinal series. The avenues on the under side of the disk and arms are rather wide, and are constructed of closely placed, compressed, more or less femur-shaped ambulacral ossicula, arranged in two series. The peculiar form of these ossicula depends on the peculiar organization of the genus, namely, the presence of four series of tentacula or suckers, a character on account of which *Uraster* is regarded as the type of a distinct family. As this character, so far as it is indicated by the ossicula, is quite preservable in fossilized starfishes, there can be little question that the following palæozoic forms, all of which present the necessary features of ambulacra and disk, are rightly referred to the genus in which I have placed them.

1. *Uraster obtusus*. F.

U. brachiis brevibus, convexis, lanceolatis, obtusis; longitudine brachiarum ad latitudinem disci ut 1·—1½: ossiculis ambulacralibus oblongis, latis, interstitiis linearibus; paginâ superiori reticulato-spinosâ.

A small species, with short obtuse convex arms, and a broad disk. Under surface exhibiting oblong rather broad ambulacral plates, decreasing slowly and nearly equal for two-thirds of the length of the arms. Avenues rather broad. Greatest diameter about an inch and a half.

This interesting form was first noticed in ashy slates at Drumcannon, county of Waterford, associated with *Phacops Jamesii*, and *Orthides*. I cannot distinguish from it a starfish found in the Bala rocks, at Moel y Garnedd, North Wales.

2. *Uraster primævus*. F.

U. brachiis brevibus, triangularibus, acuminatis, disco lato. Paginâ superiori tuberculatâ, reticulatâ (spinosâ? spinis obtusis fasciculatis?) ossiculis ambulacralibus oblongis, latis, geniculatis.

This species is of equal size and proportion of ray and disk with the *U. obtusus*, but the form of the rays is very different. The ambulacral plates are also of a different shape.

Westmoreland. [Lower Silurians.] Communicated by Professor Sedgwick and Mr. D. Sharpe.

3. *Uraster Ruthveni*. F.

U. brachiis teretibus, longissimis, angustis, subcarinatis; disco parvo; paginâ superiori reticulatâ, spinosa, spinis obtusis fasciculatis. Ossiculis ambulacralibus linearibus, longis, geniculatis.

The rays in this fine species are five times as long as the small disk is broad: they are rounded, tapering, linear-lanceolated, and subcarinated. The upper surfaces of rays and disk are reticulated

apparently with tufts and spines. The under surface is marked by the impressions of a double series of ambulacral articulations, each of which is slightly curved. Large species are about three inches and a half in diameter.

Communicated by Professor Sedgwick from the Lower Silurians of Westmoreland, where it was first observed by Mr. John Ruthven.

4. *Uraster hirudo.* F.

U. brachiis lineari-lanceolatis, acuminatis, disco minuto: paginâ superiori reticulatâ, decussatâ (spinis fasciculatis, fasciculis spinarum seriebus longitudinalibus dispositis), ossiculis ambulacralibus oblongis, ambulacris latis.

Rays four times as long as the disk, which is extremely small. The arms are tapering and linear-lanceolate, acuminated at their extremities, contracted at their bases. The spinous bundles of the upper surface are arranged in very regular rows, so that each ray appears as if marked by three or four longitudinal furrows, crossed at regular intervals by transverse grooves. Under surface with short ambulacral plates and broad avenues. The largest specimens do not measure more than an inch across. The species is gregarious, and at first glance appears rather like an *Ophiura* than a true starfish.

In the Lower Silurians of Westmoreland. Communicated by Professor Sedgwick.

5. *Uraster rubens.* L.

Mr. Searles Wood has found ossicula of starfishes in the crag which probably belonged to this well-known living species.

Foreign Species.

In the Silurian rocks of North America, several starfishes, probably of this genus, and very possibly closely allied, or even in some cases identical species with the above, have been observed. As no specimens or figures have reached England, it is difficult to judge. The best information respecting them is contained in the following notice, extracted from descriptions of American Silurian fossils, by Mr. Hall, now in the course of publication:—

" *Asterias matutina.*

" Body small, with five radiating arms; arms elongated (length twice and a half the width of the body), teeth acute, composed of three rows of plates, which join above by their lateral margins. Beneath each lateral row of plates there is an inferior lateral range visible, having the sulcus beneath the middle row, which is often depressed. The dorsal plates are somewhat hexagonal,

those of the arms quadrangular; surface punctate or granulate, perhaps from the removal of the spines covering the surface.

"The specimen is considerably crushed, and two of the arms broken off at the base; the madriporiform tubercle upon the back is not visible in our specimen. From its condition, the structure cannot be entirely made out, but it is sufficiently clear to enable any one to recognize the species.

"Three specimens of this highly interesting species are known to me, two of which occur in the Trenton limestone of New York. It bears some resemblance to the one found in Cincinnati; but it would appear, from the figure and description of Professor Locke (Proceed. Acad. Nat. Sci., vol iii. p. 33), that it is a distinct species, being at least twice as large, with the centre proportionally larger, and the plates composing the arms smaller than in our species.

"The name (*Asterias antiqua*) given by Professor Locke, is already appropriated by Troost for a very distinct species, judging from his figure (Trans. Geol. Soc. Penn., vol. i. p. 232, pl. 10, fig. 9), and probably holding a higher geological position. Professor Troost also mentions (p. 235 of the work just cited), having "found five other species of free Asterites; one of them occurring in a lower stratum than that in which the A. antiqua is imbedded, and the four others in a higher situation: all, nevertheless, below the coal." It is, therefore, quite certain that the genus Asterias existed during the deposition of the older Silurian rocks, in localities widely separated from each other, and also that the genus is represented by more than a single species."

In the third volume of the Memoirs of the Geological Society of France, there is a paper, by M. Thorent, on the geology of the department of l'Aisne, in which he gives an account and figure (pl. xxii., fig. 7) of a starfish, evidently of the genus *Uraster*, from the "Terrains anthraxiferes" of that district. He names it *Asterias constellata*, and describes the rays as elongated, acute, and irregular. The figure is not very good.

Goldfuss has figured two oolitic starfishes, specimens of which are not uncommon in English collections, and which may be referred to the genus *Uraster*. Their general aspect is very different from that of the palæozoic species and much more tropical. These are, *Asterias lumbricalis*, the arms of which are terete, long, and linear; and *Asterias lanceolata*, which has lanceolate or petaloid arms, with linear extremities.

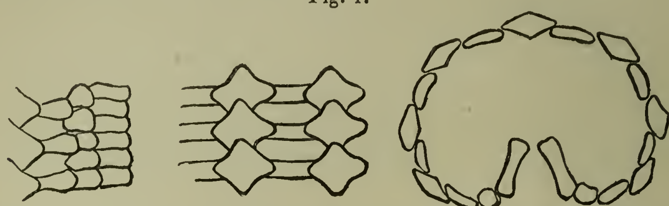
ARTHRASTER.

(αρφgον, a joint, αστηg.)

Among the examples of fossil starfishes in the rich collection of Mr. Dickson, and figured by him in his forthcoming work, there is a very beautiful and comparatively well-preserved specimen of an extinct chalk form, generically new, but nearly allied to *Ophidiaster*. It con-

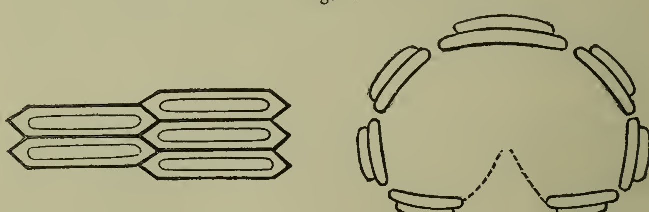
sists of the remains of several long and rounded arms, probably six or seven, radiating from a very contracted disk. The ossicula of which these arms are built are very compactly articulated together, and much fewer in number, besides being different in structure from the correspondent ossicula in *Ophidiaster*.

Fig. 1.



In *Ophidiaster* (fig. 1) the osseous framework of each arm is made up of several series of ossicula, presenting three or four modifications of form: viz., rhomboidal lenticular ossicles, of which there are seven in the transverse section, three belonging to the superior surface of the arm, and two to each of the sides; oblong or linear connecting ossicles, of which there are eight in the section, two linking the rhomboidal ossicles of the upper suface with each other, two linking the superior laterals with the surface plates, two linking the pairs of laterals on each side, and two, rather different in form, joining the inferior laterals to small quadrangular ossicles, which join on to the long femur-shaped ambulacral bones. In all, then, there are 19 ossicles in the transverse section of the arm of Ophidiaster.

Fig. 2.



In *Arthraster* (fig. 2) the number of ossicles is much less, and the arrangement different. Exclusive of the ambulacral bones, which are unknown, only seven ossicula enter into the composition of the framework of the arm, as shown in the transverse section, and these alternate in such a way as to form a compact framework without conspicuous interstices. All the seven ossicles are similar in form, consisting each of a transversely oblong expanded though linear base, terminating at each end in an acute angle, and bearing along the centre a linear crest or ridge, with steep sides. The central of the seven is largest; I regard it as equivalent to all the ossicles of the upper surface of the

arm in *Ophidiaster;* whilst the others may be looked upon as the homologues of the lateral and ventral plates, with their connecting ossicula.

The *Ophidiasters* are all tropical, with the exception of two species inhabiting the Mediterranean.

1. *Arthraster Dixoni.* F.

A. disco parvo; brachiis teretibus, cylindricis, longis; ossiculis cristatis, oblongis, regularibus, sexangularibus, articulantibus.

White chalk of the S. E. of England. [Mus. Dixon.] One specimen only is known: judging from the remains, each ray must have been nearly eight inches in length. It is figured by Mr. Dixon.

Oreaster.

This genus, as defined by Muller, in whose sense I adopt it, includes a group of pentagonal starfishes, with two rows of suckers in each avenue, and a sub-central vent on their dorsal surface, which is greatly elevated and sub-pyramidal. Their skeleton is formed of large variously-shaped irregularly-polygonal plates, disposed on the ridges of the arms in a more or less squamated fashion. Great tubercles or globular spines occupy various parts of the dorsal surface, and coronate its centre. The margins are formed of two rows of granulated overlapping plates. The interior is often strengthened by calcareous pillars. The pedicellariæ are sessile. The plates, pillars, and tubercles of the skeleton are preserved with facility in a fossil state; and as the articulating surfaces are often complicated in this genus, entire specimens or large fragments are likely to be preserved with facility.

These starfishes were styled *Pentaceros* by Linck, a name which has been adopted by Gray. They were included under *Goniaster*, in the first sketch of Agassiz. They constitute a most natural genus, confined to tropical seas. The Indian Ocean is their chief seat. All the fossil species with which I am acquainted are found in the white chalk. Figures of the following species, all of which are British, will be found in Mr. Dixon's work.

1. *Oreaster coronatus.* F.

O. disco pentagonali, crasso, convexo, coronato, brachiis productis; ossiculis disci valde irregularibus, centralibus maximis; tuberculis coronæ polygonalibus nodulosis sub-pyramidalibus.

Brachiis superne planis, ossiculis oblongis, planatis, lobulatis, protectis; ossiculis marginalibus superioribus latis, convexis, polygonatis, marginatis, punctatis, squamatis; inferioribus regularibus, elongatis, arcuatis, marginatis, oblique truncatis: ossiculis minoribus tuberculatis intermediis.

White chalk.

2. *Oreaster squamatus.* F.

O. disco pentagonali, brachiis longe productis; crasso, convexo, tuberculis polygonalibus truncatis, maximis (9), coronato; ossiculis disci lobulatis, convexis, subæqualibus.

Brachiis superne planis, ossiculis tri-lobulatis squamatis protectis; ossiculis marginalibus superioribus subreniformibus.

White chalk.

3. *Oreaster Boysii.* F.

O. disco pentagonali, brachiis productis; ossiculis tuberculisque mediocribus depressis punctatis, inferne cuneatis.

Brachiis superne planatis, ossiculis centralibus parvis, marginalibus oblongis, marginatis, in medio punctatis.

White chalk. [In the collection of the Marquess of Northampton.]

4. *Oreaster bulbiferus.* F.

O. disco pentagonali, crasso, convexo, brachiis productis clavatis; ossiculis disci subexcavatis, polygonatis, punctatis, inæqualibus, sæpe magnis: coronâ disci quinque tuberculorum compositâ; tuberculis conicis, obtusis, punctatis, inferne lobulatis.

Brachiis subcarinatis; ossiculis centralibus rotundatis, marginatis; marginalibus magnis, oblongis, lobulatis, marginatis, punctatis: extremitatibus brachiarum bulbiformibus, ossiculis quinque-serialibus planatis, punctatis, marginatis constructis.

White chalk.

5. *Oreaster obtusus.* F.

O. disco ?

Brachiis crassis, obtusis, extremitatibus oculiferis tumidis, ossiculis arcuatis, convexis, oblongis, punctatis, 4-serialibus constructis.

White chalk.

6. *Oreaster ocellatus.* F.

Ossiculis disci irregularibus, magnis, nodulosis. Tuberculis disci hemisphæricis apicibus truncatis, radiato-striatis; lateribus ocellato-punctatis.

White chalk.

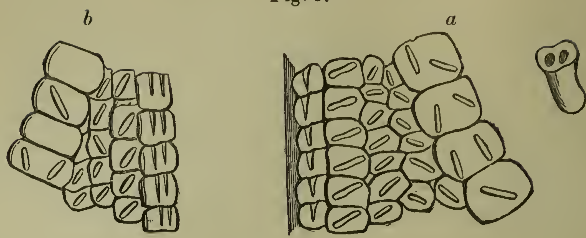
GONIASTER.

I retain this genus nearly in the wide sense given to it originally by Agassiz in his Prodromus, and prefer regarding the greater number of minor groups included within it, as subdivisions rather than as genera, whether formed on natural alliances, as in the arrangement of Muller, or upon technical distinctions of slight physiological value, as in that of Gray. Those of Muller still constitute convenient sub-genera, but I can find no characters, sufficiently constant and common to all the species

of each group, to warrant generic separation. The separation of *Asteropsis* from *Goniaster* must, however, be admitted, since the skeletons of the two genera are essentially distinct in structure.

All the members of the genus *Goniaster* have pentagonal bodies, with five angles indicating the extremities of the arms, in some species very slightly projecting, in others much produced. The disk is flat when the animal is taken out of the water, but capable of considerable convexity when alive and active in its native element. Indications of this convexity are seen in the fossil species of the section *Stellaster* (*Comptonia*). The character, " flat on both sides," which has been admitted into the generic distinctions of the *Goniasters*, is therefore adventitious, and founded only on the appearance of preserved specimens in cabinets. At the same time, the specimens of this genus are never so convex as those of *Asteropsis*, or of *Oreaster*. All the species have their margins bounded by two rows of large marginal plates, always larger than those of the back or under side. From the size and constant characters of these plates, they are very important in a palæontological point of view, both because they are capable of very perfect and easy preservation, and because they afford individually sure indications of the species to which they belong. Their surface is variously studded with granules or spines, or large pedicellariæ, and sometimes appears to have been wholly or partially naked. Muller and Troschel attempt to draw distinct lines between their genera *Astrogonium*, *Goniodiscus* and *Stellaster*, on account of the nature and disposition of the spinous appendages of their plates; but, after a careful study of numerous species recent and fossil, I find that such arrangements have no certain relations with the degree of affinity of the forms. Pedicelliferous and spiniferous plates exist equally in *Astrogonium* and *Stellaster*, and many species of the former section have exactly the same structure of marginal plate with that seen usually in species of *Goniodiscus*. At the same time, it must be remembered, that the limitation of characters derived from the structure of the marginal plates and their appendages is apparently much more constant among existing forms than among fossil, and that it is chiefly among the latter we find the connecting species. This is remarkably shown in the following representation of the structure of the marginal plates of an *Astrogonium* (fig. 3 *a*) taken by Mr. Jukes, on the north-east coast of Australia, contrasted with that of the same parts in a *Stellaster* (fig. 3 *b*) from the upper green sand of Blackdown (*S. elegans*), preserved in the collection of the Marquess of Northampton. In both we see the marginal plates furnished with large pedicellariæ, variable in number, usually placed obliquely, and fitted into grooves, which remain as if they were impressions on the beautiful siliceous cast of the fossil starfish.

Fig. 3.



Instances like the above show the necessity of excluding, as much as possible, minor characters from generic arrangements; for the very purpose of the institution of genera is, if attainable, the definition of a series of types, round which species should, as it were, be grouped, having a community of structural or major, and a variety of formal, or minor characters. The experience of naturalists goes far to show that such typical groupings have a definite relation to areas in space; and the researches of palæontologists have led us to the inference that there is a constant analogy between distribution in space and distribution in time. It is, therefore, of the greatest consequence that generic groups should be founded on natural and important, and not upon technical and variable characters. The value of palæontology to the geologist depends on the evidences it affords of the continuity of species in time, which is the evidence of unbroken sequence of conditions; and the continuity of the group, which is the evidence of sequence of design. The names of species and genera are the words of the language by means of which such general facts and laws are expressed. If these words be not precise and restricted in their meanings, definitely and not loosely used, this branch of our science can be of little scientific value. Unfortunately, the love of species-making and genus-making is too prevalent among writers on natural history, and likely to cause much confusion in the several departments of that science.

The skeleton of the *Goniasters* is composed of ossicula, which, owing to their form being tetragonal or polygonal, do not articulate firmly together. Hence we find even the best-preserved fossil examples almost always partially broken up; and specimens of existing species are very difficult to preserve if their membranous parts be at all loosened by damp. The superior disk is composed of small flat, hexagonal, pentagonal, or, more rarely, tetragonal plates, as are also the spaces between the avenues on the inferior surface. The sides are bordered, and, as it were, framed, by marginal ossicula, mostly quadrate, of considerable dimensions. The ossicula, both of margin or disk, may bear spines usually reduced to a granular form, and pedicellariæ, always sessile. The avenues are bordered by square ossicula, the surfaces of which are

marked by deep parallel grooves, varying in number, and marking the lodging-places of ambulacral spines. The marginal plates, towards the extremities of the rays, especially those of the upper side, are variously modified, often greatly enlarged, for the preservation of the eyes.

The British species of all the sub-genera of *Goniaster* are figured by Mr. Dixon in his work before cited.

Sub-genus.—*Goniodiscus.*

This section includes those species of *Goniaster* that have very short arms, or rather angles, the extreme superior marginal plates of which are modified so as to form a conspicuous eye-protecting apparatus. Were this constant, it would form a good ground for generic distinction; but the degree of its development is so variable, that, as in *Oreaster*, it can only be regarded as a source of specific character: as, however, it is very strongly presented by several species of the group, it may be looked upon as an effort, so to speak, towards the establishment of a type of generic value, and therefore as indicative of a sub-generic section.

The species of this section, besides the greater or less manifestation of the character just mentioned, have usually a definite and constant number of marginal plates between the eye-plates. This number is either 4, or 6, or 8. The eye-plates are modified laterals. In this sub-genus, the two superior laterals, which conspicuously form the angles of the disk, are often greatly enlarged, and always more or less triangular in form. Two minute plates, forming the true termination, and placed above a still minuter eye-plate, are sometimes, though rarely, preserved in fossil specimens. It is probable that these larger superior eye-plates are formed out of several ossicula, as, beneath, three at fewest correspond to them.

A. Species with four intermediate marginal plates on a side.

1. *Goniaster* (*Goniodiscus*) *Hunteri*. F.

Syn.—*Goniaster regularis*, Mantell, Medals, vol. i. p. 335, cut 73.

G. corpore pentagonali, angulis obtusis; *ossiculis lateralibus* superioribus 4, equalibus, late oblongis, mammillatis, marginatis, lateraliter punctatis. *Inferioribus* similaribus, *ossiculis ocularibus superioribus* magnis, depressis, antice latis, postice truncatis.

White chalk. Two inches in diameter.

2. *Goniaster* (*Goniodiscus*) *rugatus*. F.

G. corpore pentagonali, angulis subacutis obtusisve; *ossiculis lateralibus superioribus* 4, oblongis, convexis, subgibbosis, centraliter tuberculatis; *inferioribus* lævibus seu minute granulatis. *Ossiculis ocularibus superioribus* triangularibus, abbreviatis, gibbosis, tuberculatis.

White chalk. A small species, the largest specimens measuring about one inch in diameter.

3. *Goniaster* (*Goniodiscus*) *uncatus*. F.

G. corpore pentagonali, lateribus sublunatis; *ossiculis lateralibus superioribus* 4, latis, centraliter tumidis rugosisque, marginibus internis impressis, externis obliquis; *inferioribus* planatis, latioribus, lævibus. *Ossiculis ocularibus superioribus* acuminatis, triangularibus, mitratis, tumidis, marginatis.

An inch and a half in diameter. White chalk.

4. *Goniaster* (*Goniodiscus*) *sublunatus*. F.

G. corpore pentagonali, lateribus lunatis; *ossiculis lateralibus superioribus* 4, subæqualibus, planis, minutissime punctatis; *inferioribus?* *Ossiculis ocularibus superioribus* magnis, triangularibus, mitratis, tumidis, acuminatis.

Usually under two inches in diameter. White chalk.

B. Species with six intermediate marginal plates on a side.

5. *Goniaster* (*Goniodiscus*) *Parkinsoni*. F.

SYN.—*Asterias regularis*, Parkinson, Org. Rem. 3, t. 1, f. 3. *Tosia regularis*, Morris, Cat. p. 60.

G. corpore pentagonali, lateribus sublunatis; *ossiculis marginalibus superioribus* 6, angustatis, oblongis, subarcuatis, punctatis, angusto-marginatis; inferioribus latioribus. *Ossiculis ocularibus superioribus* triangularibus, angulis obtusis, magnis, gibboso-convexis, punctatis, marginatis.

β. Ossiculis marginalibus superioribus latis.

White chalk. Large specimens measure two and a half inches in diameter.

6. *Goniaster* (*Goniodiscus*) *Mantelli*. F.

SYN.—*Goniaster semilunatus*, Parkinson, v. iii., pl. 1, f. 1. Mantell, Medals, vol. i. p. 388, cut 75.

G. corpore pentagonali, lateribus valde lunatis; ossiculis marginalibus superioribus 6, oblongis, subcuneiformibus, convexis, ocellato-granulatis, lateraliter abruptis; *ossiculis ocularibus superioribus* triangularibus, tumidis, punctatis.

White chalk. Does not grow to the size of the last.

Foreign Species.

Goldfuss has figured, under the name *Asterias quinqueloba* (plate 63, fig. 5), fragments which belong to both the above. To prevent confusion, I think it best to reject that name altogether. He refers to Parkinson and also to Schultz (Betr. der Verst. Seesterne, 1760), whose treatise I have not been able to procure. The localities given are England, Westphalia, and Belgium.

C. Species with eight intermediate marginal plates on a side.

7. *Goniaster* (*Goniodiscus*) *Bowerbankii.* F.

G. corpore pentagonali, *ossiculis lateralibus superioribus* 8, anguste oblongis, planatis, punctatis, submarginatis: *inferioribus* similaribus; *ossiculis ocularibus superioribus* triangularibus obtusis, punctatis.

White chalk. In Mr. Bowerbank's collection.

Either to this sub-genus or the next belong certain marginal ossicula of cretaceous starfishes, which have received specific names from Desmoulins and from Agassiz, but which are quite insufficient for the establishment of species.

They are—

A. stratifera,
A. chilipora,
A. punctulata,

Desmoulins, Act. Soc. Lin. Bordeaux, t. v, 1832.

from the white chalk of France.

And—

Goniaster Couloni,
Goniaster porosus.

Agassiz, Notice sur les fossiles du Terrain cretacé du Jura Neuchatelois, in Neuchatel Transactions, vol. i.

Professor Agassiz described the ossicula to which he gives the name of *Goniaster porosus* as being more elongated than those of *quinqueloba*; their outer border broader, flat, and uniformly pitted: and *G. Couloni* as having larger, shorter, and more flattened marginal plates, their outer border much bent, strongly rounded, and ornamented with reticulating cells.

Sub-genus.—*Astrogonium.*

Muller and Troschel formed their genus *Astrogonium* for those discoid Goniasters which had their marginal plates partially (centrally) naked; a group of which the *Astrogonium phrygianum*, was the type. The character mentioned is, however, insufficient, and by no means indicates a natural section. Nevertheless, the species brought together in the "System der Asteriden" form a very natural assemblage, and one with which many fossil starfishes may be conveniently associated.

To this section I would refer those fossil Goniasters whose disk, when contracted (as always in the fossil state), becomes quite flat; whose angles are more or less produced into arms; whose marginal plates are numerous, and not regulated strictly by a determinate number; and whose eye-plates are not enormously or even conspicuously developed. The marginal plates and the ossicula of the disk may be in great part smooth, or granulated all over, or spiniferous, or stomatiferous (bearing sessile pedicellariæ), according to the species.

The fossil species of this group appear to be all, with one exception, cretaceous. The majority of existing forms occur in the Pacific and Indian Oceans: two or three distinct and well-marked forms, including the type, however, inhabit the North Atlantic even to the Arctic seas.

8. *Goniaster* (*Astrogonium*) *lunatus*. Woodward. (Sp.)

SYN.—*Asterias lunatas*, Woodward, Geol. Norf. t. 5, f. 1. *Tosia lunata*, Morris, cat. p. 60.

G. corpore pentagonali; lateribus lunatis; *ossiculis lateralibus superioribus disci* circa 12, arcuatis, gibbosiusculis, oblongis, minute lineato-punctatis, angustissime marginatis, punctis moniliformibus impressis; *inferioribus* similaribus, subtuberculatis; *ossiculis lateralibus brachiarum* parvis, oblongis.

White chalk. Measures about three inches in diameter.

Mr. Morris refers *Asterias quinqueloba* of Goldfuss to this species; but we have seen that under the name in question several specific forms were included.

9. *Goniaster* (*Astrogonium*) *latus*. F.

G. corpore compresso, pentagonali, lateribus rectis, angulis productis; *ossiculis lateralibus superioribus disci* circa 16, anguste oblongis depressis, reticulatis, punctis moniliformibus impressis; *inferioribus* similaribus; *radialibus* latioribus minoribus.

This species seems to have grown larger than the last. White chalk.

10. *Goniaster* (*Astrogonium*) *Coombii*. F.

G. corpore stellato-pentagonali, lateribus lunatis; brachiis linearibus, *ossiculis lateralibus superioribus disci* circa 20, oblongis, convexiusculis, rugoso-punctatis; *inferioribus* similaribus; *radialibus* parvis.

Measures above four inches in diameter from angle to angle. White chalk.

11. *Goniaster* (*Astrogonium*) *angustatus*. F.

G. corpore pentagonali, angulis valde productis, lateribus profunde lunatis; *ossiculis lateralibus superioribus disci* superne tumidis, punctatis, quadratis, lateraliter altis, planis, lævigatis; *inferioribus* similaribus; *brachialibus* parvis.

About the size of *lunatus*. White chalk.

12. *Goniaster* (*Astrogonium*) *Smithii*. F.

G. corpore pentagonali, angulis productis; *ossiculis lateralibus superioribus disci* superne tumidis, arcuatis, tuberculatis, punctatis, spiniferis, centralibus (circa 12) oblongis; *inferioribus* convexiusculis, punctatis; *brachialibus* quadratis.

A very large and splendid specimen, measuring about six inches in

diameter. From the white chalk. In the collection of Mrs. Smith, of Tunbridge Wells.

13. *Goniaster* (*Astrogonium*) *mosaicus*. F.

G. corpore pentagonali, angulis lanceolatis productis, lateribus lunatis; ossiculis lateralibus superioribus disci 16 angustis arcuatis, supra abbreviatis, minute punctatis; *inferioribus* similaribus: *brachialibus* parvis.

About the size of *lunatus*. From the chalk marl. In Mr. Bowerbank's collection.

14. *Goniaster* (*Astrogonium*) *Stokesii*. F.

G. corpore pentagonali, angulis longe productis lateribus profunde lunatis: *ossiculis lateralibus superioribus* disci oblongo-quadratis depressis seu convexiusculis, *brachialibus* quadratis tumidis, omnibus punctatis et ad lateras abruptis; *inferioribus* similaribus.

A species with deeply lunated sides, so that fragments may be mistaken for parts of an *Astropecten*; the arms become suddenly prolonged, and at length so attenuated that the marginal plates come in contact on their upper surfaces. The ossicula of the disk are variable in size, and strongly punctured, like those of the margin. There is a tendency in the ocular plates and their neighbours to become largely developed. Judging from the size of fragments, this species must have grown to six inches in diameter, or possibly still larger. Numerous more or less complete portions have been found in the London clay of Sheppey.

Communicated to the Geological Survey by Charles Stokes, Esq.

15. *Goniaster* (*Astrogonium*) *marginatus*. F.

G. corpore? *ossiculis lateralibus disci* magnis oblongis convexiusculis, rugoso punctatis, marginatis, margine elevato.

Although but a small fragment of this species, consisting of five ossicula and a portion of the disk, has been met with, the characters of the ossicula are so very remarkable that there can be no question as to their claims for specific distinction.

From the London clay of Sheppey. Communicated by Charles Stokes, Esq.

" *Asterias jurensis* " of Goldfuss, plate 63, fig. 6, from the oolitic strata of Wurtemberg, is a *Goniaster* of this section, and apparently distinct from any here described.

Sub-genus.—*Stellaster*.

The genus *Stellaster* was founded by Mr. J. E. Gray* for a well-known Indian Ocean species, which, however, can scarcely (if at all) be distin-

* Annals Nat. Hist., vol. vi. (1841) p. 277.

guished from the type of his genus *Anthenea*, nor do I see how *Ilosia* is to be separated.

Stellaster was redefined by Muller and Troschel thus: " Body very pentagonal and flat on both sides, with two rows of granulated marginal plates, which both enter into the formation of the steep margin. Each ventral marginal plate bears a hanging spine: the surface of the disk is studded with granulated plates. The vent is sub-central." *Stellaster Childreni*, Gray, was retained as the type. A close examination and comparison of that species, both in its fresh state (when it is *Stellaster Childreni*), and in its decorticated condition as cast ashore by the waves (*Diagona Reevii*), has convinced me that the fossil starfishes which form the upper green sand of Blackdown are very closely allied to and generically inseparable from the tropical species above mentioned. For these fossils Mr. Gray constituted his genus " Comptonia." I am, moreover, induced to refer *Stellaster* to the rank of a sub-genus of Goniaster, for except the habitually convex disk, there is no character by which we can separate it.

16. *Goniaster* (*Stellaster*) *Comptoni*. F.

G. corpore pentagonali, lateribus profunde lunatis, brachiis valde productis. *Ossiculis marginalibus* disci angustatis, in brachiis latis, punctatis regularibus, lævigatis.

This species when entire must have measured about 4 inches in diameter.

Green sand of Blackdown: in the collections of the Marquis of Northampton and Mr. Bowerbank.

17. *Goniaster* (*Stellaster*) *elegans*. Gray. (Sp.)

Syn.—*Comptonia elegans*, Gray, An. Nat. Hist. 1840, vol. vi. p. 278. Morris, cat. p. 50.

G. corpore pentagonali, brachiis productis, lateribus subrectis. *Ossiculis marginalibus* disci elongato-oblongis, punctatis, in brachiis angustis, irregulariter sulcatis, sulcis linearibus, rectis.

Green sand of Blackdown. Above 4 inches in diameter. In the collection of the Marquess of Northampton, and in the British Museum.

Foreign species. The " *Asterias Schultzii*," Römer (Versteinerungen des Norddeutschen Kreidegeberges, plate 6, fig. 21,) from the Quader of North Germany, comes so very near *Goniaster elegans*, that were it not for the absence of all traces of pedicellarian sulcations on the marginal plates represented in his figure, I should consider it identical.

PALMIPES.

(*Asteriscus*. Muller and Troschel.)

Expanded, compressed, mostly pentangular starfishes, having two

rows of suckers in each avenue, and no vent in the dorsal surface. Their skeleton is composed of small more or less pentagonal plates, those of the margin scarcely differing from and not larger than those of the disk. Most of the living species (there are about 20) are natives of tropical seas; but there is one not uncommon on the British coast, and another confined to the Arctic zone. They range to considerable depths.

No fossil starfish found in British strata can be referred to this genus; but Hisinger has figured (Lethæa Suecica, t. xxvi. f. 6) a starfish from the green sand of Gothland in Sweden, which appears to be a true *Palmipes*. He names it *Asterias antiqua*, and describes it as "A. quinqueloba angulis brevibus, apicæ obtusis, pagina inferiori reticulato-striata, radiis quinque lanceolatis." By the reticulato-striated inferior surface, he means the arrangement of the ossicula in linear series; and by the five lanceolate ridges, the peculiarly broad ambulacra presented by this apparently well preserved fossil.

It is not improbable that species of *Asterina*, a genus which closely resembles *Palmipes* in form, will be found fossil in the white chalk, judging from some loose ossicula. In *Asterina*, the ossicula of the disk are unusually trilobate and crescentic.

Astropecten.

(*Asterias* of Agassiz: *Stellaria* of Nardo.)

This genus belongs to the starfishes furnished with two rows of suckers in each ambulacrum, and having no vent. All the species are characteristically starlike; the number of rays is typically four. The upper and under surfaces are both nearly flat, but very dissimilar. Two rows of regular plates border the arms, often bearing spines, especially at their sides. The intermediate spaces and upper disk are covered with paxillæ. The ambulacral borders occupy the under surface, and are studded with numerous flattened spines.

Such a structure when fossilized is apt to present an appearance very similar to that seen in the fossil *Goniasters* of the sub-genus *Astrogonium*. But in *Astropecten*, the arms proper are not merely productions of the angles of the disk as in the former group, but occupy and form the whole border, so that the points of junction of the bases of the arms form acute angles, and not more or less lunated intermediate spaces.

Many living species of *Astropecten*, difficult to define on account of their variations, are described. They have been found in all parts of the world, but the majority live in warm climates. They live for the most part on sandy bottoms.

1. *Astropecten arenicolus*. Goldfuss.

Charlesworth, London Journ. Geol., No. 3, pl. 17.

A. radiis lanceolatis, longis, acuminatis, ad origines contractis; angu-

lis intermediis acutis; *ossiculis marginalibus* angulorum brevibus, in parte latiori radiorum maximis, angusté oblongis, in apicibus radiorum quadratis.

This species measures nearly a foot in diameter. The peculiar form of the rays, which, united by their bases at an acute angle (where the marginal plates are narrowest), then swell out into a petaloid shape, and again contract into long linear-lanceolate extremities, distinguishes it from all its congeners. Each ray is to the diameter of the disk as 3 to 1. There are about 70 plates on each side of each ray.

Marlstone of Yorkshire. It was first described and figured from the oolites of Germany.

2. *Astropecten Hastingiæ.* F.

A. radiis brevibus, lanceolatis, acutis, lateribus rectis, angulis intermediis obtusis; *ossiculis marginalibus* quadratis subæqualibus.

About 2 inches in diameter. A very beautiful star-like species, remarkable for the uniformity of the quadrate marginal plates, of which there are about 18 on each side of each ray. The length of, as compared with the diameter of, the disk, is as 1 to 1.

Marlstone? Yorkshire. Discovered by the Marchioness of Hastings, by whom it has kindly been communicated to the Geological Survey.

3. *Astropecten Orion.* F.

A. radiis lineari-lanceolatis, longis, lateribus rectis, angulis intermediis obtusis; *ossiculis marginalibus* omnibus (ossiculis angulorum exceptis) plus-minus ve quadratis, spiniferis.

Measures 8 or more inches in diameter. A very regularly stellate species, having gradually tapering arms, bordered by square plates, which decrease regularly and gradually towards the apices. Each ray is to the diameter of the disk as 3½ to 1. There are about 40 ossicula on each side of each ray.

In the collections of the Marchioness of Hastings, the Marquess of Northampton, and Mr. Bowerbank. All the specimens are from the oolites of Yorkshire.

Astropecten Phillipsii. F.

A. radiis lanceolatis, lateribus rectis, angulis intermediis valde obtusis; *ossiculis marginalibus* oblongo-quadratis, spiniferis.

A small species, measuring about 3½ inches in diameter, and strikingly resembling, in general appearance, the *Astropecten aranciacus*, var. *Mulleri*, of our seas. The rays are to the diameter of the disk as 1¾ to 1. There are about 28 ossicula on each side of each ray.

From the marlstone of Yorkshire. Communicated by Mr. John Phillips.

5. *Astropecten Cotteswoldiæ*, Buckman.

Buckman and Strickland's Ed. of Murchison's Geology of Cheltenham, p. 94, t. 3. p. 8.

A. *radiis* lineari-lanceolatis, lateribus rectis, angulis intermediis obtusiusculis; *ossiculis marginalibus* quadratis, magnis.

Ray to disk as 2 to 1. About 20 marginal plates bound each side of each ray. "Arms, five: composed of small striated joints, elongated and pointed at the extremity; disk, small. This is a very elegant Asterias, and varies in size from 1½ to 3 inches in the length of its arms. Locality: Eyeford, near Stow-on-the-Wold, in the Stonesfield slate beds. A very rare fossil, first discovered by the Rev. E. J. Witts, of Stanway."—Buckman, loc. cit.

The figure represents an *Astropecten* about 4 inches in diameter.

5. *Astropecten crispatus*, F.

Ansted, Geology, vol. ii. p. 66.

A. *radiis* late-lanceolatis, angulis valde obtusis; *ossiculis marginalibus* anguste oblongis, numerosis, spiniferis; disco lato.

About 4 inches in diameter (specimen in Mr. Bowerbank's collection). A very broad species with short arms, their length being to the diameter of the disk as rather less than 1¼ to 1. On each side of each arm there were about 36 plates. A strong spine is attached to each plate in perfect specimens.

London clay of Sheppey. In many collections. Communicated to the Geological Survey by Mr. Stokes.

6. *Astropecten armatus*. F.

A. *radiis* lanceolatis, angulis valde obtusis, *ossiculis marginalibus* oblongis carinatis, externé longé spinosis.

A fragment of a species, about the size of the last, easily distinguished by the characters of the marginal plates.

From Sheppey; in Mr. Bowerbank's and other collections. Communicated by Mr. Dixon.

Foreign Species.

1. *Astropecten Mandelshohi*, Munster.

Beitrage, 1st Heft. (1846), t. xi. f. 1, p. 98.

This species is figured very beautifully; it is described as having oblong lanceolate arms; the marginal plates oblong arcuated, slightly convex, and gradually decreasing. It approaches *A. arenicolus*, and was found in oolitic sandstone by Aalen.

2. *Astropecten priscus*, Goldfuss (sp.).

Asterias prisca, Goldfuss, Pet. Germ. pl. 63, p. 3.

An *Ophiura*-like species, with linear-lanceolate arms, from the lias of Wurtemberg. Very distinct.

3. *Astropecten propinquus*, Munster (sp.).

Asterias propinqua, Phillippi, Beitrage, s. kenntniss der Tert. Verstein. Nordw. Deutsch p. 70 (no figure).

From the cretaceous system in Northern Germany. This species is not sufficiently described.

Desmoulins has given the names of *A. poritoides*, *A. lævis*, and *A. adriatica*, to loose marginal plates of species, probably of this genus, from the tertiaries of the south of France (Act. Linn. Soc. Bourdeaux, T. V. 1832).

Luidia.

This genus was instituted by the author in 1839,* for one of the most interesting and extraordinary radiata of the European seas. It belongs to the third family of starfishes in the arrangement of Muller and Troschel, viz., those which have two series of tentacles in each avenue, but in which no vent is present. The rays are always very long and flat. A double row of large plates borders the margin, which is fringed with long spines. Paxillæ cover the disk in the living species, but these bodies (coronated spines, possibly transformed pedicellariæ) cannot be expected to be found preserved in the fossil state. The living Luidiæ are remarkable for the facility with which they can break their bodies into fragments. The known species are inhabitants of northern and tropical seas.

An unique fossil starfish appears to belong to this genus; it is figured and described by Mr. Williamson in the 9th vol. of Loudon's Magazine of Natural History for 1836. Not having seen the specimen, I extract the description entire. The species will stand as *Luidia Murchisoni*. Williamson (sp.):—

"This fossil was found in the marlstone at the point where it is carried up into the cliff, to the north of the great fault, at the Peak Hill near Robin Hood's bay, near the lower part of the stratum, where it blends with the lower lias. The figure represents the object reduced to two-thirds of the real size. The slab on which the fossil is preserved is of a rather micaceous nature, a matrix, generally unfavourable for preserving minute characters; and a portion of the fossil having adhered to the upper part of the rock, which fell in pieces, the view presented is rather that of the internal than the external structure of the animal. The central circle, the situation of the mouth, is preserved very distinctly; and proceeding with considerable regularity from this, is a series of rays 20 in number. Those rays near their base bear the sulcus (furrow), which runs under those of recent Asteriæ; but towards their apex they become more worn and thin, showing, in several places, a small wiry line, with short ribs branching off at right angles, appa-

* Wernerian Memoirs, vol. viii. pt. 1.

rently a species of appendage, resembling what represents the vertebral column and ribs in the turtle, and which is observable in recent Asteriæ. There are also slight traces of transverse grooves on the whole surface of each ray; but these are generally almost obliterated. Along the margins are extremely regular rows of small rhomboidal perforations, or cells, from which proceed a series of lateral filaments, or delicate lengthened papillæ; but on the surface of the fossil, it merely presenting to us the interior, no papillæ are preserved. The apex of such rays as have not been broken off prior to the animal being entombed are obtusely pointed."

Table of Fossil Asteriadæ.

	Genus.	Species.	Formation.	Locality.	Reference.
PALÆOZOIC	Uraster .	obtusus, n. s. . . .	Lower Silurian	Ireland. N. Wales.	
	——— .	primævus, n. s. . .	——— ———	Westmoreland.	
	——— .	Ruthveni, n. s. . .	——— ———	——— ———	
	——— .	hirudo, n. s. . . .	——— ———	——— ———	
	———? .	matutina, Hall . .	——— ———	United States	Hall, Pal. N. Y.
	———? .	antiqua, Locke . .	——— ———	——— ———	Proc. Ac. N. S. Phil. vol. 3.
	———? .	antiqua, Troost . .	——— ———?	——— ———	Tr. Geol. Soc. Pen. vol. 1.
	——— .	"five other species," Troost . . .	——— ———?	——— ———	Ditto.
	——— .	constellata, Thorent. .	Terrains anthraxiferes.	N. of France	Tr. Geol. Soc. Fr. vol. 3.
LOWER SECONDARY.	Uraster .	lumbricalis, Goldf. .	. .	Germany .	Petrif. Germ.
	——— .	lanceolata, Goldf. . .	. .	Germany .	——— ———
	Goniaster .	jurensis, Goldf. . .	. .	Wurtemberg	Petrif. Germ.
	Astropecten	arenicolus, Goldf. . .	Marlstone .	Yorkshire . Germany .	Petrif. Germ. Charlesw. Journal.
	———	Hastingiæ, n. s. . .	Marlstone .	Yorkshire.	
	———	Cotteswoldiæ, Buckman.			
	———	Orion, n. s. . . .	Marlstone .	Yorkshire.	
	———	Phillipsii, n. s. . .	Marlstone .	Yorkshire.	
	———	Mandelshohi, Munster.	Oolites . .	Aalen . .	Munst. Beitr. 1st Heft.
	———	priscus, Goldfuss . .	Lias . . .	Wurtemberg.	
	Luidia .	Murchisonii, Williamson	Marlstone .	Yorkshire .	Mag. N. Hist.
UPPER SECONDARY.	Arthraster	Dixoni, n. s. . . .	White Chalk .	S. of England	Dixon.
	Oreaster .	coronatus, n. s. . .	White Chalk .	———	———
	——— .	squamatus, n. s. . .	——— ———.	———	———
	——— .	Boysii, n. s. . . .	——— ———.	———	———
	——— .	bulbiferus, n. s. . .	——— ———.	———	———
	——— .	obtusus, n. s. . . .	——— ———.	———	———
	——— .	ocellatus, n. s. . .	——— ———.	———	———
	Goniaster .	Hunteri	——— ———.	———	Mantell, Medals.
	——— .	rugatus, n. s. . . .	——— ———.	———	Dixon.
	——— .	uncatus, n. s. . . .	——— ———.	———	———
	——— .	sublunatus . . .	——— ———.	———	———
	——— .	Parkinsoni . . .	——— ———.	———	Parkinson.
	——— .	Mantelli	——— ———.	———	
	——— .	Bowerbankii, n. s. .	——— ———.	———	Dixon.
	——— .	lunatus, Woodward .	——— ———.	———	Woodward, Geol. Norfolk.
	——— .	Coombii, n. s. . .	——— ———.	———	Dixon.
	——— .	angustatus, n. s. .	——— ———.	———	———
	——— .	latus, n. s. . . .	——— ———.	———	———
	——— .	Smithii, n. s. . . .	——— ———.	———	———
	——— .	mosaicus, n. s. . .	Chalk Marl .	———	———
	——— .	elegans, Gray . .	Green Sand .	Blackdown .	Dixon.
	——— .	Comptoni, n. s. . .	——— ——— .	——— .	———
	——— .	Schultzii, Römer . .	Quader . .	Germany .	Römer Kr.
	Palmipes .	antiquus, Hisinger .	Green Sand .	Sweden .	Leth. Suecica.

Table of Fossil Asteriadæ—continued.

	Genus.	Species.	Formation.	Locality.	Reference.
	Astropecten	propinquus, Phillippi .	Green Sand ? .	Germany .	Phill. Beitr.
	(Doubtful sp. orrepetitions)				
	Goniaster .	quinqueloba, Gold. .	White Chalk .	Germany, &c.	Petr. Germ.
	——— .	Couloni, Agassiz . .	Chalk Marl ? .	Neuchatel .	Neuf. Mem. I.
	——— .	porosus, Agassiz . .	——— .	——— .	———
	——— ?.	stratifera, Desm. . .	Chalk . .	France .	Bourdeaux Tr. t. v.
	——— ?.	chilipora, Desm. . .	——— . .		
	——— .	punctulata, Desm. .	——— . .		
Tertiary ,	Uraster .	rubens, Lin. ? . .	Crag . .	Suffolk	S. Wood.
	Goniaster .	Stokesii, n. s. . .	London Clay .	Sheppey.	
	——— .	marginatus, n. s. . .	——— .	———	
	Astropecten	crispatus, n. s. .	——— .	——— .	Ansted, Geol.
	———	armatus, n. s. . .	——— .	———	
	(Doubtful species)				
	Astropecten	poritoides, Desmoulins .	Tertiaries .	S. of France.	Bord. Tr. vol. 5.
	———	lævis, Desmoulins . .			
	———	adriatica, Desmoulins .			

Note.—Cœlaster, Agassiz, appears to me not to belong to the Asteriadæ, nor do the bodies named by Goldfuss, *Asterias scutata*, *A. stellifera*, and *A tabulata.*

On the Cystideæ *of the Silurian Rocks of the British Islands.* By Edward Forbes, Esq., F.R.S., Professor of Botany in King's College, London, and Palæontologist to the Geological Survey of the United Kingdon.

Among the many additions which the progress of geological research has given to British palæontology within the last four years, few are more remarkable than the discoveries which have been made among the *Cystideæ,* an order of radiated animals of which no undoubted species was recorded in our lists, even so lately as the date of the publication of that useful document, Morris's Catalogue of British Fossils. Indeed the creatures composing this order were but little known anywhere, though not a few examples of them had occurred in the Silurian strata of the North of Europe, where they had been observed as long ago as the time of Linnæus, and even before. Their nature, however, was misunderstood, or the notions of their zoological affinities but confusedly perceived, until the philosophic Von Buch undertook to investigate their structure and relations; the result of his inquiry was the production of an admirable and beautifully illustrated essay "Uber Cystideen," published at Berlin in 1845. This gave a new impulse to the study of and search for these bodies: and the account I here give of our British species, brought to light partly by the researches of the Geological Surveyors, and partly by the intelligent and able lovers of geology who do honour to the town of Dudley, had its origin in the interest excited through the perusal of Baron Von Buch's memoir.

The progress of our knowledge of British Cystideans has been indeed remarkable, and dates from the account by Mr. Channing Pearce, in 1843, of a remarkable and anomalous fossil discovered by Mr. Fletcher at Dudley, and named by the former gentleman *Pseudo-crinites.* So strange did this body seem that its true nature was quite misunderstood at the time, and having a knowledge of it only through bad figures, I was one who doubted the correctness of the observations, and believed it would probably prove to be either a monstrosity or the rudimentary condition of some crinoid. When Mr. Griffith published the "Synopsis of the Silurian Fossils of Ireland," in which his rich collection was described by Mr. M'Coy, a cystidean was made known so near to, if not identical with, certain forms found in the North of Europe, that general attention was directed to the subject. An examination of the extensive collections of Silurian fossils brought together by the Geological Surveyors during their exploration of South Wales showed many fragments of more than one genus of *Cystideæ*, though in a bad state of

preservation. The examination of the Bala Limestones, in which I personally assisted, in 1846, brought to light many interesting bodies of the same class. In the mean time new and remarkable forms were discovered at Dudley and Walsall, so that there was rapidly brought together a great mass of material for the history of a tribe of extinct beings which hitherto had played no part in British Geology. There is every prospect of many more new and curious species being discovered. The Geological Survey in Ireland has, during the autumn of 1847, added to our knowledge of the order. With the data on hand, however, it is desirable no longer to delay the publication of an account of our British cystideans, which are now comparatively numerous, not only as to species, but even as to genera, and include forms so novel and curious as importantly to affect the received notions respecting their true affinities and structure.

The history of the successive observations which have been published upon the bodies included in this order has been so fully treated of by Von Buch, in the memoir cited, and by De Verneuil, in his account of the Palæontology of Russia,* that I do not consider it necessary to review it here, and reserve such comments as I have to offer on the conflicting opinions which have been put forth respecting the zoological position of the *Cystideæ* until after the following description of our British species. In order, however, that such description may be clearly understood, it is necessary to preface the synopsis of the species with an examination of the several organs and parts common to all or the greater number of *Cystideæ*.

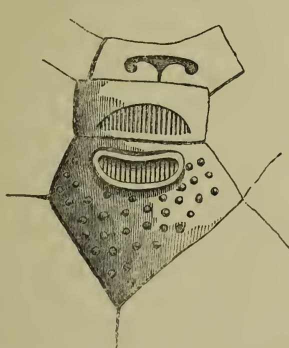
SECT. 1.—OF THE STRUCTURE OF THE CYSTIDEÆ.

The *Cystideæ* are more or less sphærical bodies covered with polygonal plates, varying in number according to the genus, closely fitting together so as to invest the entire surface with a compact coat of mail, except at four points, viz., inferiorly, where the body unites with a stem; centrally, or above the centre, on one side, where there is an opening closed by valves, supposed with good reason to be the orifice of the reproductive system; and superiorly where the mouth is found, usually if not always with a small perforation, supposed to be a vent, alongside of it. These parts, viz., the plates investing the body, the three orifices (for the fourth perforation, that of the base, is continuous with the canal of the stem where the latter is well developed), and probably the stem, are common to all *Cystideæ*. There are other parts, apparently of great consequence in the organization of the animal, which are common only to certain members of the order. These are

* Murchison, De Verneuil, and Keyserling, 'Geology of Russia,' vol. ii.

the brachial appendages (arms and tentacula) and certain curious organs or appendages connected with the plates, to which the name of *pectinated rhombs* may be appropriately given.

Orifices.—All the Silurian cystideans appear to have usually, if not always, three orifices, viz., a mouth; an opening contiguous to the mouth, which may be regarded as an anus; and a third orifice closed by a pyramid of plates or valves, which there is every reason for believing to be the opening of the reproductive organs. The mouth is terminal, superior, and central, being placed at the opposite pole to the base, or point of affixment. It varies much in form and size. In *Sphæronites*, it appears to be small and circular; in *Caryocystites* more or less elongated transversely and lobed; in *Hemicosmites* it is placed at the extremity of a plated proboscis; in most *Echino-encrinites* it is longitudinal, running in an anteal and posteal direction, and is bordered by peculiar plates; in the Cystideans provided with arms, it appears to be a circular opening round which those appendages arise. There is reason to believe that the unarmed species were in the habit of pouting out and retracting their mouths, causing considerable change of form of the whole body in consequence. Near the mouth a small orifice, which from analogy may be regarded as anal, is evident in *Sphæronites*, but is not distinguished by any peculiarity in the arrangement of plates. A similar orifice, often prominent, is seen in *Caryocystites*. In *Echino-encrinus* (at least in our British species) there is upon one of the small oral plates of the right side, an arched or crescentic groove terminating apparently at each end with a pore, and having either united with it or placed a little below it, an orifice in the line of a suture, as if in the junction of two oral plates. This arrangement is placed immediately over the semi-rhombiferous plate (one of the supra-ovarian series) No. 15, as may be seen in the accompanying sketch from a specimen in the collection of Mr. Lewis of Wolverhampton.



A similar arrangement of crescentic groove surmounting a pore in

the suture of two small plates is clearly seen in *Apiocystites* placed centrally on the right side between two of the arms, and holding a corresponding position with that it maintains in *Echino-encrinus.* Indications of a like structure occur in *Pseudocrinus.* That the pore beneath or combined with the groove corresponds with the supposed anus of *Sphæronites* is evident when we look at the form it assumes in *Echino-encrinites baccatus,* where a considerable orifice holds exactly the corresponding position with respect to the mouth, though in *Sphæronites* itself, that position is not so constant, and in *Agelocrinites* the anal opening is placed posteally above the ovarian pyramid, a position which it appears to hold also in the cystidean figured by Volborth as *Protocrinites oviformis* (Tr. Min. Soc. Petersb., 1845-6, pl. x. f. 8). I think it very probable, that this anal opening will be found in all the cystideans, though from the imperfection with which the parts about the mouth are often unfortunately preserved, it is likely to escape notice in many instances. I cannot think it is ever combined with the ovarian opening as has been supposed, indeed, we have seen that it is present in certain species of *Echino-encrinites,* the genus wherein such a peculiar arrangement was supposed to occur.

" Further towards the middle," says Von Buch, " but almost invariably on the upper half of the body on which the mouth is placed, there rises a round or oval aperture, not connected with the mouth, and often covered by a five or six-sided pyramid, which seems to be composed of as many little valves. This probably forms the ovarial orifice of the animal." All that I have seen among the British Cystideans goes to bear out fully the important view taken by the distinguished naturalist just quoted. This ovarian pyramid is one of the most curious and distinctive features of the *Cystideæ,* and separates them most markedly from the *Crinoideæ.* The valvular structure is very evident in many of the forms described in this memoir, and appears to be constant, for the doubt which has been thrown upon its constancy, in consequence of the apparent absence of a pyramid and valves in the foreign species of *Echino-encrinites,* will be seen to have risen from the defects of the specimens examined ; for in some of the British species of the same genus, the pyramid and its parts are perfectly preserved, and we cannot suppose that a character so important in the organization of the creature, was variable in any one genus. The valves of the pyramid appear to have been firmly articulated, or even anchylosed in some genera, as in *Sphæronites,* where we find their summits perforated, probably for the extrusion of the eggs (as is the case in the ovarian plates of the *Echinidæ*), or for the passage of the impregnating fluid in the male. In *Echino-encrinus* there appear to be no such perforations ; and, as we find in this genus that the valves of the pyramid were perfectly free

from each other, there was probably no necessity for such an arrangement, since the extrusion of the reproductive products might have been easily effected by the slight opening of the valves. I can trace no perforations in the ovarian valves of *Pseudocrinites* and *Apiocystites*, in which genera they appear also to have been free. In all the genera with unperforated valves (unless *Hemicosmites?*), the base of the ovarian pyramid is surrounded by a circle of small supplementary plates, an arrangement which probably aided the opening and closing, pouting out and retracting of the valves. The number of the latter appears to be never fewer than five nor more than six; the number of supplementary plates forming the circa-ovarian ring varies, but is generally 9 or 10.

The position of the ovarian pyramid appears to be very constantly on the upper half of the body, and subcentral. It is always placed opposite one end of the mouth, wherever the mouth is elongated. In rhombiferous cystideans, whenever there are three rhombs, two of them flank the ovarian pyramid, and the third is on the opposite side (or anteal extremity), and placed on a lower plane. In those genera which have their bodies composed of definite arrangements of plates, it has constantly the same position with respect to the great plates near it. Hence it is evidently an organ of no small importance in regulating the symmetry of the bodies in which it occurs.

Plates.—The plates which compose the exoskeleton of the *Cystideæ*, are always either pentagonal or hexagonal, or imperfectly tetragonal, and are so arranged as to join completely, leaving no interspaces, except for the orifices essential to the animal's economy. They are very variable in number, in some forms (as in the genus *Sphæronites*), being extremely numerous and disposed without apparent order; in others (the majority of genera), being limited and definite in number, and very regularly and constantly arranged. They may be divided into such as form the base of the body (the basal series); such as are arranged on a plane beneath the ovarian pyramid, and between it and the base (the sub-ovarian series); such as are on the same plane with the ovarian pyramid (the centro-lateral series); such as are arranged on a plane superior to the ovarian pyramid (the supra-ovarian series); such as immediately surround the mouth (the oral plates); and such as encircle the ovarian pyramid (the circa-ovarian plates or ossicles). With the exception of the basal series, each of these appears to be composed of several similar sub-series in the genera *Sphæronites* and *Agelocrinites*. Six small plates form the pelvis in the former, five or six in the latter genus. In the foreign genus *Cryptocrinites*, the base is composed of three plates. In all the other genera, having a limited and definite number of body plates, the basal series is composed of four plates. According as we regard the point of insertion of the stem as a truncation or not, there

are either some pentagonal or some hexagonal, or else some tetragonal and some pentagonal. Preferring the former view, I shall describe them accordingly. With the exception of *Caryocystites* and *Hemicosmites*, which have two hexagonal and two pentagonal basal plates, all the British genera have a base composed of three pentagonal and one hexagonal plate. One of the superior angles of the hexagonal or large plate—the left angle—points towards the ovarian pyramid, and the pentagonal plate opposite usually bears the half of a pectinated rhomb. As this arrangement holds good in many genera (*Echino-encrinites*, *Prunocystites*, *Pseudocrinites*, and *Apiocystites*), I have adopted a scheme of numbering the plates, for the better facilitating of the description and comparison of the species. Regarding the ovarian pyramid as *posteal* in position, the semirhombiferous plate opposite will rank as anteal, the other two pentagonal plates ranking as left and right. When all the series are projected on a plane, I count the anteal plate as 1, that to its left as 2, the posteal or hexagonal plate as 3, and the right plate as 4: then proceeding spirally onwards, the second series commences with a hexagonal plate, bearing the other half of the pectinated rhomb, of which one half is upon plate 1 (the anteal basal plate); this first plate of the second series is lateral and anteal, and counts as 5: the lateral and anteal plate to the left of it, also hexagonal, ranks as 6, as its two lower sides unite with plates 1 and 2: then follows the third plate of the second series, a large hexagonal plate, emarginated on one of its sides for the reception of the ovarian circle: this is plate 7; its two lower sides unite with 2 and 3 of the basal series; it is posteal and lateral. The fourth plate of the second series is pentagonal, its base fitting on the broad side of the posteal hexagonal plate of the basal series; it ranks as plate 8. The fifth and last plate of the second (sub-ovarian) series, is large and hexagonal: its two lower sides unite with 3 and 4 of the basal series. It is centro-lateral and right in position, and counts as plate 9. The third or centro-lateral series is likewise composed of five plates, of which the first is the hexagonal plate numbered 10, the two lower sides of which unite with sides of 9 and 5 in the second series: 11 is placed above 5 and 6: 12 follows above 6 and 7, sometimes semirhombiferous, though, in some cases, the semirhomb is placed upon 13, a plate which forms the upper and left border of the ovarian opening. Plate 14, the last of the centro-lateral series, is usually more or less elongated transversely, and is generally rhombiferous, the corresponding half of the rhomb being placed on plate 15, the first of the uppermost or supra-ovarian series. The number of plates in this series is variable, sometimes being four; sometimes complete, and five. Their forms are also much more variable, even in individuals of the same species, than those of the plates of the three lower series. The plates of the oral series are small, and very irregular in shape and number.

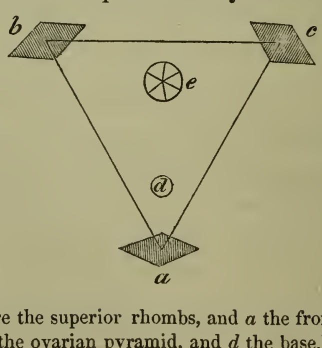
The surfaces of the plates of most Cystideans are more or less ornamented with grooves, striæ or rugosities, and in some cases marked with pores, either scattered singly or in pairs, when they are often linked together by a groove. From the centre of each plate, in most cases, proceed more or less distinct radiating ridges or grooves, which pass into, and are continuous with, those of the neighbouring plates, so that the patterns formed by their union are continually being repeated over the surface of the body, so as to render it very difficult to define the plates in such species as have them without distinct margins. Sometimes (especially in *Hemicosmites*) the central and radiating ridges are more or less broken into rows of tubercles, and the interspaces are transversely grooved. The appearance of twin pores is seen in several species of *Caryocystites*. In some species of *Echino-encrinus*, the radiating character of the ornaments of the plates is nearly obsolete, and the surface appears as if irregularly rugose. In *Pseudocrinites*, the two characters of radiation and rugosity are combined.

Baron von Buch has discussed the subject of the ornamental sculpture of the plates in *Cystideans*, and has shown how the law of its arrangement is identical with that which regulates similar sculpture in the Crinoids, so fully in his memoir on the Cystideæ, that little is left to add or illustrate. It is probable that the arrangement of the grooving and striation bears throughout a relation to the distribution of rows of vibratile cilia over the external surface of the body, comparable with that recently observed by Professor J. Müller in the larvæ of *Echinidæ*, and which I shall presently show gives a clew to the nature of the very curious plate-ornaments which we have next to describe.

Pectinated Rhombs.—In the species of the genera *Pseudocrinites, Apiocystites, Prunocystites,* and *Echino-encrinites*, certain of the body-plates bear curious organs, to which the above term has been applied. They were first observed and delineated in the Russian species of *Echino-encrinites*, in most of which, however, judging from the figures (for I have seen no foreign specimens of members of this genus), they are very imperfectly or obscurely exhibited. In the British species of *Pseudocrinites* and *Echino-encrinites*, they are developed strongly and in great perfection. Each rhomb consists of two halves; each half is borne on a separate plate. The two portions are more or less triangular, or sometimes reniform, so that when placed base to base they form a more or less defined rhombic figure. The centre of each half is usually more or less depressed, though sometimes on a level with the surface of the plate, and is marked with transverse and parallel sulcations, often very deep, varying in number in different species, and in the several rhombs of each. These sulcations are longest in the centre of the half-rhomb, and gradually decrease towards each extremity. The intervening ridges are usually about the same breadth with the furrows. The series of

sulcations are often bordered by a raised rim or thickened margin, which defines the outline of the rhomb. This is wanting, apparently, in the foreign Cystideæ in which rhombs are figured, and is almost obsolete in some of the British. More frequently the margin of one half-rhomb is fully developed, whilst that of the other, and even the sulcated part, is aborted. The half-rhomb, as a whole, corresponds to one of the triangular striated divisions of the plate upon which it is placed, one of the straight edges of the plate forming its base. Very generally, however, it is contracted much within the dimensions of such division, and appears in a few cases even to extend beyond it. When well-developed, it bears little resemblance to any part of the plate upon which it is placed. Nevertheless it may with great probability be regarded as one of the segments of the plate metamorphosed. The sulcations do not seem to perforate the plate. The section of a specimen of *Echino-encrinites prunum*, in the collection of Mr. Capewell, figured in our plate of that species, exhibits a very curious appearance, as if the striæ or sulcations penetrated to different and regular distances in the substance of the body, those of the centre piercing deepest. I am inclined, however, to regard this appearance as dependent rather on some peculiarity in the mineralization of the specimen than on true organic arrangement.

The number of these rhombs varies. In *Pseudocrinites* and *Apiocystites* there are invariably three; in *Echino-encrinites,* two or three. The number in *Prunocystites* is not yet made out. I have never met with more than three in any Cystidean. Whenever there are three, one, which I have termed the *basal rhomb*, is placed in front, and has its lower half upon the first basal plate, and the upper on the first plate of the second or sub-ovarian series; the other two are placed high up, at each side of the ovarian pyramid (therefore at the right and left sides of the body), and rather above it, so that, if a line be drawn from one to the other, and two other lines drawn to connect each with the basal rhomb, we have, when we project the plates on a plane, a triangle, of which the first line is the base. This may be regarded as the typical arrangement of the rhombs, and be represented by the following diagram :—



[In the cut *b* and *c* are the superior rhombs, and *a* the frontal and basal rhomb: *e* is the ovarian pyramid, and *d* the base.]

The purpose of these rhombs, and their true nature, is very difficult to determine. At first glance it might seem as if they were the analogues of the bodies which in the American *Caryocrinites* are regarded as aborted arms. But the shape, arrangement, and position upon the plates of the supposed arm-cups of *Caryocrinites*, on close inspection, do not answer in any respect to the pectinated rhombs of *Pseudocrinites* and its allies. That they are the usual ornamental grooves and striæ of the plates, in part metamorphosed, we have already regarded as probable. But what purpose did they serve, and where are we to seek their homologues among other Echinodermata? I have never met with organs comparable with them in any section of this extensive class of animals. In the account recently given by Professor J. Muller, of Berlin, of the larvæ state and metamorphoses of the *Ophiuridæ* and *Echinidæ*, he notices certain epaulette-like organs, studded with vibratile cilia, in the supposed larva of *Echinus*, which may possibly be analogous to our pectinated rhombs. "The distribution," he states,* "of the ciliated organs is very peculiar. These larvæ are furnished with oblique tufts, resembling epaulettes, which are situated upon those spots where the four supports of the dome pass into it; the tufts are covered with very long moving cilia; a thick mass of sulphur-yellow pigment lies beneath the tufts. Moreover, these larvæ are furnished with a row of cilia upon all the columns, and on the dome itself, as is the case with the *Pluteus* (*i.e.*, the larva of *Ophiura*). Two rows run upon each column; these run into one another at the extremity, and superiorly at the dome, from one ray to the others. * * * The columns also between which the mouth and œsophagus are situated, are covered with a row of cilia, which passes from one ray to the other on the same side, and in the centre runs beneath the mouth from one side to the other." It is very probable that the radiating grooves on the plates of the Cystideans marked the course of permanent or possibly deciduous lines of cilia, and that the greater development and concentration of these at special and fixed points were the features now indicated by the pectinated rhombs. If I understand Muller right, the relative position of the ciliated epaulettes in the larva of *Echinus*, with its mouth, and a five-valved disk which is developed heterologous to the mouth, would be not unlike that maintained between the pectinated rhombs, the ovarian pyramid, and the mouth in *Echino-encrinites* and its allies. Should it prove so when the development of the *Echinidæ* shall have been better known and illustrated, an important clew would thereby be given to the true relations of the *Cystideæ*, and the position in the animal series which I assign to

* 'On the Larvæ state and Metamorphoses of the *Ophiuridæ* and *Echinidæ*,' by Prof. J. Muller. Translated by Dr. Griffith from the Proceedings of the Berlin Academy for 1846. Annals of Nat. History, June, 1847.

them in this memoir borne out by the anamorphosis of the superior group.

Appendages.—Under this head may be described the arms and the oral tentacula, organs which are not universal among the *Cystideæ*, but confined to a few genera, viz., *Pseudocrinus*, *Apiocystites* and *Agelocrinus*, all of which have arms; and *Prunocystites* (and according to Volborth two species of *Echino-encrinus*, but which will probably prove distinct from that genus), having oral tentacles.

The nature of the arms in such *Cystideæ* as possess them, is an inquiry of some consequence, the more so as a controversy has arisen between M. Von Buch and M. Volborth, on the question whether *Cystideæ* have arms at all, the latter affirming that they have, the former denying the correctness of M. Volborth's inferences. The organs, however, which gave rise to the discussion, are those which I have just designated oral tentacula, though tentacles of a very extraordinary structure, being regularly articulated filamentary bodies, each composed of a double series of calcareous joints. They are quite unique in character, and I know not what to compare them with, unless the arms of *Ophiuræ*, especially of those species with much attenuated appendages. Arms, in the sense of crinoidal arms, however, they assuredly are not. They are articulated around the mouth, and appear to be four in number. (Volborth on Echino-encrinus in the Bulletin de la classe Physico-Math. of the Acad. Sc., St. Petersburgh, tom. iii.) I have described similar bodies in the very curious Dudley fossil, for which I have proposed the name of *Pruno-cystites*. Eichwald (Die Urwelt Russlands, pl. i. f. 10 *a* and *c*.) has figured tentacula-like bodies in two groups around the mouth in an *Echino-encrinus*, but their position with respect to the neighbouring plates as represented in his figure, is such, that in this case I should suspect some mistake. Not so, however, with Volborth's figures, which are very excellent and clear.

Had the *Pseudocrinus* been known at the time the discussion arose, it might well have been supposed that the Cystideans, or at least certain forms of them, were furnished with arms like those of Crinoids. For in that genus we have regularly formed arms two or four in number, of considerable size, symmetrical, and constructed of complicated joints, which bear regularly articulated calcareous fingers similar to the hard oral tentacula first observed by Volborth. Similar arms (the fingers have not been observed) occur in *Apiocystites* and in *Agelocrinites;* in the former genus the number being four, in the latter five. That these arms, however, whatever shape they may assume, are essentially distinct in their nature from the arms of Crinoids, a close examination and consideration will show. They are organs which are developed from

the ventral or oral pole of the body, and not from the dorsal, as in the Crinoids. They are reflected towards the base, not directed from base to mouth as in the latter order. They are in fact, free ambulacra, like the greater part of the arms in *Ophiuridæ* and *Euryalidæ*, and essentially the same with the arms of *Pentremites*. The important indications they afford of the true affinities and zoological position of the Cystideans we shall see hereafter.*

Stem.—All the rhombiferous Cystideæ, whether with or without arms, were provided with a stem of considerable dimensions. Such appears, also, to have been the case with *Agelocrinites*. The armless Cystideans without rhombs appear to have been fixed, either constantly, or at an early period of their lives; but the true nature of these stems, which in most cases were probably small, is not evident. We find no traces of them in British examples, though the point of affixment is very conspicuous in the dorsal or basal surfaces of the bodies. In our native species of *Echino-sphærites* and of *Pseudocrinites*, the stems have been very perfectly preserved with the bodies attached. They are constructed exactly as the stems of Crinoids, and are cylinders formed of successive ring-shaped joints, which usually become broader but thinner as they approach the base of the cup or body. They vary not only in thickness, but also, in some instances, alternate in size; so that a moniliform aspect is given to the stalk. Sometimes the external surface of the joints are keeled, and the keel being placed beneath the centre of their circumference, an appearance is presented slightly resembling that presented by the anomalous fossil called *Cornulites*. The structure, however, is essentially different. This appearance seems to have misled M. Volborth and others into the notion, that the *Cornulites* was the stem of a Cystidean, a conclusion altogether opposed to that which the very perfectly-preserved stem of the British Cystideans indicate.

* Volborth maintains, however, that the bodies which he regards as arms are developed from the dorsal pole, and not from the ventral. He explains his view thus:—"All the Cystideæ were, like Crinoids, provided with articulated arms; and this statement is not mere hypothesis, but is the result of philosophical induction from distinct well-grounded facts, determined by observation—by the actual presence of arms in some species, and the presence of tentacle furrows in others. The Cystideæ are also *true Crinoids*. Either in the young state or throughout life they were attached by an articulated stalk, or by a pedicle either to the bottom or to foreign bodies. They had articulated arms, which, as in Crinoideæ, proceeded from the dorsal pole of the cuticular skeleton. Diametrically opposite to the orifice for the pedicle is placed the buccal orifice, and generally close to it is the sub-central anal orifice. The cup differs, however, from that of the Crinoids, by such a predominance of the dorsal side over the ventral that the latter is often reduced to a minimum, consisting only of the orifice of the mouth, so that the arms appear to be much nearer the mouth than is the case with Crinoids."—Volborth, on the Arms of Cystideæ. Trans. Min. Soc. of St. Petersburgh. 1845-6.

SECT. 2.—DESCRIPTION OF THE SPECIES.

All the *Cystideæ* found in British Silurian strata may be arranged under the following heads:—

A. Bodies composed of definite numbers of plates.

a. With arms and pectinated rhombs. (Upper Silurian.)

Pseudocrinites.

Apiocystites.

b. Armless; with oral tentacula and pectinated rhombs. (Upper Silurian.)

Prunocystites.

c. Armless; oral tentacula wanting; pectinated rhombs present. (Upper Silurian.)

Echino-encrinus.

d. Armless; no rhombs; bodies composed of four series of plates, exclusive of the oral plates. (Lower Silurian.)

Hemicosmites.

e. Armless; no rhombs; bodies composed of more than four series of plates, exclusive of the oral plates. (Lower Silurian.)

Caryocystites.

B. Bodies composed of an indefinite number of plates.

a. With arms; no rhombs. (Lower Silurian.)

Agelocrinites.

b. Without arms; no rhombs. (Lower Silurian.)

Sphæronites.

I shall now proceed to a detailed account of the species.

PSEUDOCRINITES, Pearce.

Among the numerous important and interesting fossils discovered by the naturalists of Dudley, scarcely any are more curious and, in a zoological point of view, more important, than the extraordinary crinoid-like bodies, to which the late lamented Mr. Channing Pearce gave the name of *Pseudocrinites*, and which form some of the most precious ornaments of the rich collections of Mr. Fletcher and Mr. Gray.* Their

* "During the past quarter, several very beautiful and perfect specimens have been discovered of that peculiar fossil to which your curators alluded in the first Report, as partaking of characters allied both to the pentremite and encrinite, although essentially

true nature was first perceived by Baron von Buch, who, in his Memoir on the *Cystideæ*, when he had a knowledge of them only from Mr. Pearce's account, referred them in a concluding note to the *Cystideæ*, and suggested their affinity with *Caryocrinites*. The account of them, which is here given, will show how correct such a view of their position was, though, to an ordinary observer, they seem at first glance far removed from their relations.

The genus *Pseudocrinites*, as I propose to restrict and redefine it, includes such *Cystideæ* as have a more or less orbicular body, composed of a limited and definite number of plates, arranged in four successive series; a distinct ovarian orifice closed by a depressed pyramid of triangular ossicula; pectinated rhombs on two or more parts of the external surface, each half of each rhomb being placed on a separate plate; arms, two or four in number, radiating from an apical mouth, and folded back upon the sides, resting, *but not buried*, in very shallow grooves so that they project considerably above the surface; articulated fingers, the number and length of which varies in the several species, fixed upon the arms throughout their length, and placed in a double row on the sides of a straight groove; a stem, similar to the stem of a crinoid, composed of compressed rings which decrease rapidly in size and become thicker, as they are more and more distant from the base of the body to which the stem is affixed. Besides the oral orifice, the form of which is obscure in all the specimens I have examined, there was probably an anal orifice placed on one side of the mouth, beneath a small semicircular groove.

I am acquainted with four distinct species of the genus so defined. These I shall now proceed to describe. Two of them have but two arms, the other two have four. One of each section was described and named by Channing Pearce.

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different from either. From the specimens which were laid before the meeting, it was seen that the body is composed of irregularly-shaped plates. It is divided into four parts, by bands apparently running down from the top of the body, and reaching nearly,—in some specimens fully,—to the point where the column and body join. In some instances, two of these divisions are larger than the others, and may be called the front and back of the fossil; the two smaller divisions forming the sides. It is, however, possible that this apparent irregularity, which is not evident in every specimen, may result merely from unequal compression. Each of the four bands possesses a double row of small rays; and one of the great peculiarities of this fossil is the presence of some curious slits, or openings, in the plates of which the body is composed. One of these slits is to be found in each of the four parts into which it is divided, situated alternately in the upper and lower portions of the divisions. What purpose these openings may have answered it is difficult fully to understand; but they are evident in all the specimens known, and must have performed some important function in the animal economy of the living individual. This fossil differs both from the pentremite and encrinite, in being divided into four parts instead of five."—'Report of the Dudley Museum,' 1843.

1. *Pseudocrinites bifasciatus*, Pearce.

Pearce, in Proc. Geol. Soc. London, vol. iv., p. 160.
Pseudocrinites bicopuladigiti, Pearce, in Athenæum, No. 803; extracted, and figures copied, in Garner's Natural History of Staffordshire, p. 160.

Body circular, very much compressed, the sides nearly flat or slightly convex; a thick plane margin upon which the arms rest, surrounds the body. The composition of the body is as follows:—

The base is formed of four plates, three pentagonal and one hexagonal; the left angle of the latter pointing towards the ovarian orifice. Of these plates, the anteal or No. 1 bears half a pectinated rhomb, and is placed so that it occupies the central base of the side opposite to that upon which we find the ovarian pyramid. A part of No. 4 is placed to its right, and is bent to form the base of the posteal sub-brachial margin. On the ovarian side, the principal basal plate is No. 3 (the hexangular basal), on the right of which we see a part of No. 2, which is bent to form the greater part of the base of the anteal sub-brachial margin. Of the second series of plates (or sub-ovarian), No. 6 forms the central on the frontal side, and is flanked by 5, bearing the half of a pectinated rhomb to correspond with that on the basal plate No. 1 and 7, both of which, however, go in part to form the sub-brachial margins. On the ovarian or posteal side 8 and 9 are fully exposed, and a small part of 7 and 5, which plates, therefore, have three faces each. The third (or centro-lateral) series consists anteally of 12, fully exposed; 13, exposed in part, and bearing the half of a pectinated rhomb; and part of 11, on the posteal side of 14, bearing the half of a pectinated rhomb, and 10. No. 14 is a very long plate, and joins in part the ovarian circle. Of the upper or supra-ovarian series, 15, containing the other half, the pectinated rhomb of which one half is on 14, is fully exposed on the posteal side. No. 18 bears the half of the pectinated rhomb corresponding to that on No. 13. Nos. 16 and 17 are plates partially exposed. The ovarian orifice appears to consist of eight circa-ovarian ossicula surrounding a depressed pyramid of six triangular ovarian valves.

All the plates are ornamented with radiating ridges and intermediate rugose striæ. They are all more or less bordered with a ridge. Those portions of the plates which go to form the brachial margins of the body, present no traces of radiating ridges, but are marked with dovetailing raised striulæ, which correspond with the ossicula of the arms. The interspaces of these are quite smooth.

There are three pectinated rhombs, each composed of a pair of triangular or slightly reniform transversely grooved furrows, with a raised bordering ridge; each half of each rhomb placed on a separate

plate. The rhomb on plates 14 and 15 is larger than the rest. Corresponding with it, but smaller, is the rhomb on plates 13 and 17. These two form a triangle with the basal rhomb, the half of which are placed on plates 5 and 1. The number of transverse sulcations distinctly indicated in the latter, is twenty-two.

The arms, two in number, extend down the flattened margins of the body, but not quite to the base in all specimens. They are each composed of cuneiform ossicula, alternately larger and smaller, arranged in a double series, and the larger members of each series alternately with each other. Each pair, small and large, of brachial ossicles forms a base for a finger, constructed of small alternately cuneiform ossicula, gradually diminishing to the extremity. The fingers are about four times the length of the diameter of the arms, which are as 1 to 2½ of body. The number of fingers on each arm is from 12 to 16, according to size of specimen.

2. *Pseudocrinites magnificus*, Forbes.

In Mr. Gray's collection is an unique specimen of a Pseudocrinite, allied to the last, but very distinct, and of much larger dimensions. Mr. Gray had recognized it as a distinct species. The anteal side only is exposed.

It is extremely compressed, even more so than the last species, and circular. The plates are beautifully radiately ridged, with intermediate rugosities and cross-bars. Those exposed are, 1 and 4 of the basal series; 5, 6, 7 of the sub-ovarian series; 12, 13, and part of 11 of the centro-lateral series; and 16, 17, and 18? of the supra-ovarians. These are arranged and shaped exactly as the corresponding plates in *Pseudocrinites bifasciatus;* so that the relative position of parts and arms are the same in both species. On plates 1 and 5 are the two halves of a pectinated rhomb; also on 13 and 18. These rhombs are remarkable for their extreme angularity, especially the basal one. There are about 30 bars and sulcations in each half of each rhomb. On the summit, above plate 17, are traces of anal plates and of an anal orifice.

The arms extend completely down the sides, and are remarkable for the great number of fingers on each, being no fewer than thirty-four. They are much more closely packed, longer, slenderer, and apparently more flexible, than in the last species.

The proportions of parts in this species are as follows: —

Breadth of body to height, as 1 to 1.
Breadth of arm to breadth of side, as 1 to 5.
Breadth of arm to length, as 1 to 7.
Joints in arm, 34 × 2.

The actual dimensions are—

Length, $1\frac{1}{2}$ inch; the breadth is the same.
Length of fingers, $\frac{5}{16}$ inch.

The stem is gone.

3. *Pseudocrinites quadrifasciatus*, Pearce.

Pearce, in Proc. Geol. Soc. London, vol. iv., p. 160.
Pseudocrinites quadricopuladigiti, Pearce, in Athenæum, No. 803, extracted, and figures copied in Garner's Natural History of Staffordshire, p. 160.

This species has four arms. The body is tetragonal, the arms resting on the four truncated angles. The sides vary in their dimensions in different specimens, in some being all nearly equal, in one or two, two of them being much wider than the other two. These differences do not appear to indicate distinction of species. On three of the sides pectinated rhombs are present, one on each; on the fourth side is the ovarian orifice. Hence the latter may be described as the posteal, the opposite one as the anteal, and the other two aspects as left and right. In such specimens as are compressed the narrow sides are the anteal and posteal. The basal pectinated rhomb is on the anteal side, the upper rhombs on the left and right, the ovarian pyramid of course on the posteal, and placed upon its upper third. The basal rhomb is the shortest, and is placed obliquely, its upper end towards the right. The rhomb of the left side is the largest, being lanceolato-triangular, and is placed very obliquely. That of the right side is of intermediate dimensions, rather wide, and placed nearly transversely. All the plates are radiately and rugosely ridged and grooved. The ridges, as in other cystideans and crinoids, pass from the centre of the plate to that of the next. The plates are also more or less marginated. All those plates which are beneath the arms, and so form the truncated angles of the body, are smooth, except those parts which indicate, by fine elevated ridges, the resting-places of the ossicula of the arms.

The arms are strong, quadrangular, and highly elevated. They usually extend nearly to the base; but there is a short-armed variety, in which they cease about two-thirds of the length of the body from the mouth. They are obtuse. The ossicula composing them are very numerous, and arranged as in *P. bifasciatus*. The fingers are also very numerous, about 28 in each arm, and formed of fine alternating polygonal ossicula, which are much smaller than those of the species next to be described. The fingers folded over each other when at rest, their apices towards the centres of the arms, so that their length did not exceed the diameter of the arm. The oral orifice was in the centre of

the four arms. An anal orifice was probably present on the summit of one of the sides.

The stem was of considerable length. Its upper part, near the body, was formed of broad thin circular perforated plates, which rapidly and regularly diminished, changing into thicker rings, alternately larger and smaller, and at length into small but thick cylindrical joints.

Although several very excellent specimens of this curious species exist, there is not sufficient material to make out the arrangement of the plates completely. They appear, however, to have corresponded exactly with those described in *P. bifasciatus.* Of the additional pair of arms one passed on the angle between the ovarian pyramid and the rhombiferous plate 14, dividing the latter, and crossing and covering the greater part of plate 8. The other arm crossed plate 12, and covered the suture between plate 6 and the rhombiferous plate 5. The remaining two arms held nearly the same position with those in the two-armed *Pseudocrinites.*

The ovarian pyramid is obscure in all the specimens I have examined. It was depressed, and composed of six triangular valves.

The proportions of the nearly equal-sided variety, are as follows :—

Breadth of body to the length, as 1 to $1\frac{1}{8}$.
Breadth of side to length of side, as 1 to 2.
Breadth of arm to breadth of side, as 1 to 2.
Breadth of arm to its length, as 1 to 4.
Ossicula of arm, 28×2.

The dimensions of the largest specimens I have seen, are—

Length of body, $\frac{7}{10}$ inch.
Greatest breadth, $\frac{6}{10}$ inch.
Breadth of stem at junction with body, $\frac{3}{10}$ inch.
Breadth of arm at midway, $\frac{2}{10}$ inch.

There are specimens of this species in the collections of the Marquess of Northampton, Mr. Fletcher, Mr. Gray, Mr. Day, and in that of the late Mr. Channing Pearce.

4. *Pseudocrinites oblongus*, Forbes.

In the collections of Mr. Gray and of Mr. Fletcher, there are several fine specimens of a four-armed Pseudocrinite, which might at first glance be confounded with small specimens of the last-named species, from which, however, they are very distinct.

The body of the *Pseudocrinites oblongus*, by which name I propose to designate this new form, is ovato-tetragonal, and slightly more tumid above than below. The sides are nearly equal. The plates are rugosely reticulate, with more or less distinct radiating ridges. On three of the

sides pectinated rhombs are placed, exactly as in the last species. That of the right side has the upper half nearly obsolete, the sulci only being present, whilst the lower half is strongly developed. The ovarian pyramid is much depressed, and composed of six triangular ossicula, two of which (the uppermost) are rather narrower than the rest, and seem as if they were formed out of one divided.

The arms are much narrower than in the last species, and become narrow suddenly, their bases being broad. Their structure is similar; the joints of which they are composed are proportionably larger and fewer; the fingers they bear are very long in proportion to their breadth.

The relative proportion of parts is as follows:—

Breadth of body to length, as 1 to $1\frac{1}{2}$.
Breadth of side to its length, as 1 to $2\frac{1}{2}$.
Breadth of arm to breadth of side, as 1 to $1\frac{1}{2}$.
Breadth of arm to its length, as 1 to 5.
Joints in arm, 21 × 2.
Sulcations in each half of basal rhomb, 19.
Sulcations in each half of the oblique superior rhomb, 32.

The actual dimensions of the largest specimen met with, is—

Length of body, $\frac{6\frac{1}{2}}{10}$ inch.
Breadth, $\frac{3}{10}$ inch.
Breadth of arm, $\frac{1}{10}$ inch.
Breadth of column at union with body, $\frac{1}{10}$ inch.

The joints of the column, which is of considerable length, are not so broad towards the base, as in *P. quadrifasciatus*. The upper twelve are thin, and gradually decrease; below that they become thicker, narrower, and more cylindrical.

The essential characters of the genus *Pseudocrinites*, and of its several species, may be summed up as follows:—

Pseudocrinites.

Corpus orbiculare, bi-seu-tetragonum, rhombiferum, angulis truncatis; brachia duo vel quatuor, exserta, appressa; sulci brachiales recti.

Os rotundum? apicale; anus lateralis, sub-apicalis; ossicula ovariales sex.

Assulæ basales 4; infra-ovariales 5; centro-laterales 5; supra-ovariales 5; apicales?

Basis plana; columnâ longa, crassa, cylindrica, prope basim tumidâ.

1. *P. bifasciatus.*

P. corpore compresso, bilaterali; brachiis duobus linearibus, 20 × 2

tentaculatis articulatisque: columnâ prope basim corporis valde tumidâ.

In strato Siluriano prope Dudley. (Mus. Gray, Fletcher, Capewell.)

2. *P. magnificus.*

P. corpore compresso, bilaterali; brachiis duobus linearibus, 34 × 2 tentaculatis articulatisque.

In strato Siluriano prope Dudley. (Mus. Gray.)

3. *Pseudocrinites quadrifasciatus.*

P. corpore inflato, quadrangulari, suborbiculari; brachiis quatuor lanceolatis, 28 × 2 tentaculatis articulatisque; columnâ prope basim valde tumidâ.

In strato Siluriano prope Dudley. (Mus. Northampton, Gray, Fletcher.)

4. *Pseudocrinites oblongus.*

P. corpore oblongo; quadrangulari, brachiis quatuor linearibus; 20 × 2 tentaculatis articulatisque; columnâ prope basim tumidâ.

In strato Siluriano prope Dudley. (Mus. Fletcher, Gray.)

APIOCYSTITES.

In the collection of Mr. Gray, of Dudley, there is a single specimen of a cystidean, closely allied to the *Pseudocrinites*, and at first glance appearing as if a species of that genus, though strikingly different from those which I have just described. It is oblong and tetragonal, the four sides being nearly equal and flattened; the four angles planed off and slightly grooved for the reception of as many arms, which proceed from the rather acute apex, and run down the whole length of the body. On one of the sides, above its centre, is a depressed but sufficiently conspicuous six-valved ovarian space; on each of the other three, at positions similar to those in which they occur in *Pseudocrinites*, are a pair of small pectinated spaces, each pair forming an imperfect rhomb. The base is truncated, and the body becomes slightly narrowed towards it. The column is absent, but there is sufficient evidence that it was of considerable dimensions.

A minuter examination yields the following results. The body is composed of a like number and arrangement of plates with that we have described in *Pseudocrinites*. The base is formed of four plates, one of which is hexagonal, and the other three pentagonal, two of them being wide in proportion to the third. The right superior angle of the (third or) pentagonal basal plate points to the ovarian orifice, and a straight line drawn from it upwards follows the course of the suture between the two hindermost plates of the second series (viz., 7 and 8), and joins the central of the lower circa-ovarial plates. Plates 3, 7, 8,

13, 14, and 17, with the ovarians and circa-ovarians, go to the formation, either wholly or in part, of the posteal or ovarian side. The number of circa-ovarians is obscure, but the ovarians, which are broad and much depressed, are distinctly six. I could see no perforations in them. The anteal side is mainly composed out of plates 1, 5, 10, 11, 16, with parts of 6, 4, and 17. Plates 1 and 5 bear each the half of a pectinated rhomb. The right side is chiefly composed of plates (in whole or part) 3, 4, 9, 14, 10, and 15. Of these, 15 and 14 bear each the half of a pectinated rhomb. The left side is formed of plates 2, 6, 7, 13, 17, and 18, of which 13 and 18 bear each the half of a pectinated rhomb.

All these plates form four successive series, the basal composed of plates 1, 2, 3, 4; the next in order, or sub-ovarian, of 5, 6, 7, 8, and 9, which are as a whole the largest series; the centro-lateral of 10, 11, 12, 13, and 14; the supra-ovarian of 15, 16, 17, and 18. The formula of the whole would therefore stand, B. 4 + 5 + 5 + 4. There are oral plates also, but too obscure for definition. All these plates appear to have been radiately and granulosely striate, but the specimen is worn so as to appear smooth.

The four arms are linear, and as long as the body. They are lodged in as many shallow grooves truncating the angles of the body. They fit in the grooves, and are not elevated above them. They are composed of two series of alternating and opposing ossicula, those of each series themselves alternately broad and narrow. A deep grove, having sixteen short lobes or notches, alternating and oblique, on each side, runs between them, and from these notches doubtless proceeded the fingers, which may have been calcareous, as in *Pseudocrinites*, or possibly only soft. The manner in which the arms are lodged in the grooves, and the peculiar mode of the articulation of the ossicula, differ too essentially from that presented by the three cystideans which we have described under *Pseudocrinites* to admit of the union of the species before us with that genus, although the structure of the body is similar, which, however, as we shall presently see, is also the case in the very different *Echino-encrinites.*

There is reason to think that the mouth was similarly shaped, probably four-lobed, with the mouth of the *Echino-encrinites.* On the right side, at the angle nearest the mouth, there appears to be a reniform groove, placed above and at the union of two sub-apical plates, the suture between which unites with the upper angle of the rhombiferous plate No. 15. This reniform groove forms a semicircle above an indistinct pore, an arrangement which closely reminds us of that seen in *Echino-encrinites*, and which I have considered, in the account of our British species of that genus, as an excretory or anal apparatus. The position exactly corresponds, the supposed anal orifice in the last-named genus

being also placed at the junction of two small sub-apical or circa-oral plates surmounting plate 15.

The pectinated rhombs are much smaller than in the *Pseudocrinites*. They are composed of two somewhat reniform bodies, with transversely grooved (pectinated) centres. Those of plates 13 and 18 are largest; they have only seven grooves. The two halves of each rhomb are nearly equally well marked.

The proportions of parts in this Cystidean are as follows:—

Breadth of body to length, as 1 to $1\frac{1}{2}$.
Breadth of side to length, as 1 to $1\frac{1}{2}$.
Breadth of arm to breadth of side, as 1 to $1\frac{1}{2}$.
Breadth of arm to length of arm, as 1 to 5.
Joints in arm, $17 \times 2 \times 2$.

I propose to name this genus *Apio-cystites* (ἄπιος, a pear, in allusion to the fruit-like form), and define it as follows:—

Apiocystites.

Corpus oblongum, tetragonum, rhombiferum, angulis truncatis, excavatis; brachia quatuor, plana, in sulcis angulorum inclusa; sulci brachiales oblique-lobulati.

Os transversum, apicale; anus lateralis, sub-apicalis; ossicula ovariales laterales sex.

Assulæ basales 4; infra-ovariales 5; centro-laterales 5; supra-ovariales 5; apicales?

Basis plana, columna?

Sp. *Apiocystites pentrematoides.*

(Mus. J. Gray) in Strato Siluriano superiori prope Dudley.
[Specimen unicum. Lon. $0\frac{6}{8}$ unc. Lat. $0\frac{3}{8}$ unc.]

Prunocystites.

The very singular and interesting fossil to which I have given the name of *Prunocystites*, is one of the gems of the beautiful collection of Silurian fossils in the possession of Mr. Fletcher of Dudley. It is a small ovate cystidean, with a very large stem attached, and presenting the remarkable feature of possessing long tentacula or filamentary arms, not folded back and lodged in grooves, as in the *Pseudocrinites* and its allies, but projecting directly from the oral aperture, around which they appear to have been attached.

Unfortunately the specimen is so imbedded in stone, that our description of it must necessarily be extremely imperfect. One side of the body is exposed, a considerable portion of the stem, and part of three

or perhaps four finger-like arms. The body is ovate, and shaped like the fruit of a dog-rose. Its surface is marked by raised anastomosing ribs, forming hexagonal and pentagonal divisions, which appear to indicate the margins of the plates, and to be formed out of their swollen edges. If so, there are three main series of plates, and one imperfect apical set. The basal series probably consisted of four, the centro-lateral and supra-lateral of five each. The basals were mostly pentagonal, one (not exposed in the specimen) probably hexagonal: all the laterals exposed are hexagonal. On one of the superior lateral plates there is an imperfectly indicated pectinated rhomb. The apical plates appear to have bordered a transverse mouth, on the edges of which were articulated the calcareous tentacula, each composed of alternating and dovetailing ossicula. The mode of union of the fingers with the apical plates is not distinctly seen, but their connexion with the body cannot be questioned. Those fingers which are visible are not all of equal dimensions, one of them being much finer than the others. They appear to be analogous to the fingers, and not to the arms of *Pseudocrinites*. The stem is very large in proportion to the body, and consists of compressed joints, alternately larger and smaller. Those nearest the body are largest. They rapidly diminish downwards.

The length of the body is only an inch. The breadth is to the length as 1 to $1\frac{1}{4}$. The side exposed appears to be the left. If so, the central plate seen in the figure must be equivalent to No. 9 of *Pseudocrinites*, flanked by parts of 8 and 5, and borne by the basal plates 2 and 3. The rhombiferous plate is probably the equivalent of No. 14, and that to its right of No. 10.

I have named it provisionally *Prunocystites Fletcheri*.

In Mr. Gray's collection there is a small, much-worn, berry-like cystidean, which appears to have a similar structure of body, and probably belongs to the same genus, if not to the same species.

Echino-encrinus.

During recent excavations at Walsall, a number of specimens of new and remarkable Cystideans were brought to light. They presented, with some modifications, the characters which were assigned by Von Meyer to his genus *Echino-encrinites* (the *Gonocrinites* of Eichwald, and *Sycocystites* of Von Buch); which, in some respects, has hitherto been misunderstood, in consequence of the comparative imperfection of continental examples.

Both British and foreign *Cystideans* of this genus present the following characters in common: the body is formed of four series of polygonal plates, surmounted by an additional series of curiously-formed oral

plates or ossicles. The basal pelvic series consists of four plates, three pentagonal and one hexagonal. The sub-ovarian and centro-lateral series of five plates each; the supra-ovarian of either four or five. There are always pectinated rhombs present. The number of oral ossicles is variable. The mouth is transverse, and there is an anal opening by its right margin. The body is borne upon a stem of considerable dimensions.

The British species differ from the foreign in several respects. All the latter have the ovarian orifice placed on the lower half of the body, without, however, being differently placed with respect to the plates around it. If it had been so, we must have regarded such difference as generic; but as it is, can look upon it only as specific. The ovarian orifice is further stated, in continental examples, to have no valves or plates; but I have already shown how this apparently important difference is really owing to the looseness of the ovarian valves in this genus, and the consequent facility with which they are lost. The notion of Volborth, that the ovarian aperture served for an anus as well, a view which is taken by De Verneuil,* is also contradicted by the undoubted presence of an anus or anal pore in the British specimens, as well as by the improbability of an arrangement so exceptional in this order. A further difference is stated with respect to the stem, which in the continental species is said to be elastic and contractile, and formed of tubes inserted into each other, in the manner of the divisions of a telescope, so as to present the exact appearance of Cornulites, and to lead to the notion that that fossil is only the stem of an Echino-encrinite, is contradicted by the well-preserved stems of the Walsall species so strongly, that I cannot but think there is some mistake or confusion in the account given of the stems of this genus, as observed by Volborth; and that the interpretation of that account given by Von Buch, in his description of *Sycocystites*, is the correct view.

The foreign species have, moreover, their rhombs but slightly marked as compared with the British, in which they are remarkably conspicuous. Von Buch, in his description of the *Sycocystites angulosus* describes two pectinated rhombs, as indicated in that species: "a singular and finely striated basal plate, and a similar finely striated segment of a plate placed diametrically opposite, between the ovarian orifice and the mouth." His figure represents them as imperfectly defined. The positions, however, agree exactly with those of the corresponding rhombs in our British species. In Schlotheim's figures of his "*Echinosphærites granatum*,"† which is the *Sycocystites striatus* (Pander) of Von Buch, two of the rhombs are pretty distinctly indicated. Vol-

* Palæontology of Russia, p. 27.

† Oken's Isis for 1826, pt. 3, t. 1, f. 1 *a*, *b*, and *c*.

borth (in the Bulletin of the St. Petersburgh Society, vol. x. p. 19, f. 4, 5, 6,) has shown them plainly, figuring three, and indicating their true positions. They are very indistinct in the figures of *Echino-encrinites striatus*, given by De Verneuil (in the Paleontology of Russia, pl. 1, f. 5*a*, *b*), and a little more evident in that of *Echino-encrinites angulosus* (in the same work, pl. I, f. 6 *a*, *b*, *c*). Whilst the rhombs are thus comparatively indistinct on the continental *Echino-encrinites,* the radiating striæ on the surfaces of the plates are conspicuously developed, so much so as to render the divisions or sutures of the plates difficult to observe. The reverse is the case with our British species.

The whole structure of the *Echino-encrinites* recalls that of *Pseudocrinites.* The arrangement of the plates, and the position with respect to the ovarian pyramid, the structure of that pyramid, and the structure and disposition of the pectinated rhombs, are almost identical in both genera. This is especially satisfactory, since it furnishes indubitable evidence of the close affinity of *Pseudocrinus*, with the armless Cystideans on the one side, whilst on the other it enables us to trace the relationship which undoubtedly exists between the latter and the *Pentremites*, through *Pseudocrinus.*

Species of the genus *Echino-encrinus* have hitherto been found only in Russia and in the United States of America.

Echino-encrinus baccatus, Forbes.

Body oval, cylindrical, tumid towards the oral extremity, formed of well-defined irregularly rugose plates, distinctly separated from each other by depressed and strongly marked sutures. Plate 1, of the basal series, projects at its left upper side to meet plate 5 (in the sub-ovarian series); both are semi-rhombiferous, but the half-romb on plate 1 is comparatively indistinctly marked, and the border surrounding it not very strongly defined. The half-rhomb on plate 5 is very prominent, oval, surrounded by a strong elevated smooth rim, so as to give it a cup-like aspect; the transverse grooves within the cup are from six to eight in number. This cup-shaped half-rhomb occupies very nearly one-half of the surface of the plate upon which it is placed. The other plates of the sub-ovarian series are not remarkable; plate 7 is much larger than its fellows. In the centro-lateral series, plates 12 and 14 bear semi-rhombs, the corresponding halves of which are borne on plates 13 and 15 of the supra-ovarian series. The rhombs so formed stand at nearly equal distances from the ovarian aperture; their centres upon a rather higher plane. In fact the lower half-rhombs are largest and most cupped; strongly rimmed, and occupying great part of the plates upon which they are placed. They are nearly equal, though not quite alike in outline; about eight transverse grooves are present in each. The upper half-

rhombs are not so strongly marked, their rims being slightly elevated, and the cups not so deep. Their transverse striæ are carried on over the suture up the side of the rims of the lower half-rhombs. It may be noted, that in the two upper rhombs it is their lower halves which are most developed, whilst in the basal rhomb the reverse is the case. The rugosities, or irregular granulations of the surfaces of the plates, do not appear to bear any distinct relation to the grooves of the rhombs.

The oral plates are so arranged as to form a circle, or rather an indistinct pentagon, bounded by the upper margins of the five plates of the supra-ovarian series, and the upper margin of plate 13, the right angle of which is excavated or emarginated to form part of the supra-ovarian arch. The oral ossicles are very prominent and tubercular. They seem to vary in number in different individuals, but in the specimen best preserved there are four on one side of the mouth and three on the other. In the midst of the three last is the anal aperture, larger than usual in this species. The mouth is transverse, and somewhat semicircular. It is placed obliquely with respect to the ovarian aperture. The latter orifice is small and placed in a gentle depression. It is above the centre of the body. The circa-ovarian ossicles are small, and about 10 in number. The plates of the ovarian pyramid are deficient in all the specimens as yet found.

The stem is strong, tapering, and conic, composed of rings, which are angulated at their edges. They rapidly decrease and become larger as they are more distant from the base.

Of this beautiful fruit-like form there are several well-preserved specimens; one in the cabinet of Miss Jukes, of Birmingham; one in that of Mr. Buckman; one in Mr. Gray's collection; and one, the least perfect, but very interesting on account of the appearances exhibited by its fracture and the dimensions of its stem, in the collection of Mr. Capewell. They have all been found in the Wenlock formation either of Dudley or of Walsall.

Dimensions of largest specimen:—

Length, $\frac{1}{2}$ inch.
Breadth, $\frac{3}{8}$ inch.
Length of mouth, $\frac{3}{16}$ inch.
Breadth of ovarian aperture, $\frac{1}{8}$ inch.
Thickness of stem at base, $\frac{3}{16}$ inch.

Echino-encrinus armatus, Forbes.

Body somewhat quadrate, broad, laterally compressed, formed of distinctly defined radiato-granulated plates; those of the second series bearing a prominent central spine or tubercle. Basal series forming an expanded cup, the frontal plate (No. 1) bearing an indistinctly

marked semi-rhomb, the centre of which is slightly depressed beneath the surface plane, and marked by close transverse grooves, 16 or 18 in number. The corresponding half-rhomb is placed on the first plate (5) of the second series, and is a deep oblong cup, with a prominent rim; the grooves in its centre as numerous as on the half-rhomb of plate 1. All the plates of the second series are remarkable for an oblong, elevated, steep-sided, spine-like, rugose central tubercle. Plates 14 and 15 (of the centro-lateral and supra-ovarian series), each bear the half of a pectinated rhomb, similar to the basal rhomb in its arrangements, but longer, and in this case the less perfect half is uppermost. A corresponding rhomb is in some specimens placed upon plates 18 and 12; in others it is wanting. The plates are all ornamented by small granulations, which are more or less conspicuous in different specimens. These are arranged in rows parallel to the sides of the plates; those near the margin are in many cases closer than the others, and placed in more distinct lines, so as to form a head or border to the plate. There are indistinct traces of radiating lines or gentle ridges, proceeding from the centre to the margin of the plates.

The oral ossicles are variable in number, and mostly more or less oblong and quadrangular in shape. They form a narrow rim bordering the much compressed linear, transverse, as if two-lipped mouth, which, at its ends, projects or is let into emarginations of two of the supra-ovarian plates, viz., Nos. 11 and 13. The amount of this emargination varies much in different specimens. In one very fine specimen (in Mr. Fletcher's collection), there is an appearance along the margin of the mouth as if of the bases of tentacula. The anal orifice is placed on one side of the mouth, the right side, subcentrally; two plates (or perhaps three in some cases) border it, and it is surmounted by a crescentic groove, as described in the account I have given of the vent among the Cystideans generally. In the specimen just alluded to, the anal orifice presents a very peculiar appearance, as if it were constructed of a flexible bottle-shaped body, formed of a different substance from the rest of the cup, and having its orifice downwards, arched over which is the usual semi-lunar pore.

In the same specimen the ovarian orifice and its ossicula are well preserved. The pyramid consists of five lanceolate plates or ossicles, in shape strikingly like the oral teeth of an *Echinus*. The upper ones are rather larger than the lower, so that the pyramid stands out somewhat obliquely, and as if with a downward direction. In some specimens the number of its ossicula is six. The circa-ovarian ossicles are small, and mostly tetragonal; the upper ones largest. There are usually about 10 of them. The ovarian orifice is small as compared with the mass of the body.

The upper part of the stem is well preserved in a stem belonging to Mr. Buckman; it is composed of narrow carinated rings, decreasing from the base very gradually.

There are several varieties of this species. Most of the specimens which I have seen have only two of the rhombs developed, viz., the basal and right ones. In Mr. Lewis's collection is a fine specimen, with all these well developed. It varies also in the proportion of the large tubercles to the plates upon which they stand. In a specimen of Mr. Buckman's these occupy a very considerable part of the plate, but their relative proportion, as compared with the body, seems to have diminished as the animal grew in size. Most of the existing specimens are much compressed from slight crushing, but when unharmed the body is rather tumid, though its transverse dimensions are never equal to the longitudinal.

Dimensions of largest specimen :—

Height, $\frac{6}{8}$ inch.
Length, $\frac{5}{8}$ inch.
Breadth, $\frac{4}{8}$ inch.
Length of mouth, $\frac{4}{8}$ inch.
Breadth of ovarian aperture, $\frac{1}{6}$ inch.
Thickness of stem at base, $\frac{2}{8}$ inch.

All the examples in collections have been found in the Wenlock shale at Walsall. Fine specimens exist in the collections of Mr. Gray and Mr. Fletcher, of Dudley, Mr. Lewis, of Wolverhampton, and Mr. Buckman.

The essential characters of the genus *Echino-encrinites*, and its British species, may be summed up as follows :—

Echino-encrinites.

Corpus subcylindricum, rhombiferum, brachiis nullis.

Os apicale, transversale ; anus lateralis, subapicalis. Ossicula ovariales 5 vel 6.

Assulæ basales 4; infra-ovariales 5; centro-laterales 5; supra-ovariales 4 vel 5 ; apicales, 8-10.

Basis plana ; columna longa, crassa, cylindrica.

1. *E. armatus.*

E. corpore lateraliter compresso lato, assulis infra-ovarialibus in medio tuberculatis, ossiculis oralibus parvis, ore compressimo lineari.

In strato Siluriano superiori prope Walsall (Mus. Fletcher, Gray, Buckman, Lewis, Capewell).

2. *E. baccatus.*

E. corpore baccato, cylindrico, tumido, assulis omnibus reticulato-rugosis; ossiculis ovarialibus magnis, ore oblongo.

In strato Siluriano superiori prope Walsall et Dudley (Mus. Jukes, Fletcher, Gray, Capewell).

Hemicosmites.

In the Transactions of the Mineralogical Society of St. Petersburgh for 1845-6, Volborth has figured* three separated plates of a Cystidean, which he regards as belonging to the genus *Hemicosmites*. Bodies very similar to that represented occur not unfrequently in the lower Silurian rocks of Wales and Ireland.

The genus *Hemicosmites* was established by Von Buch for a fossil figured by Pander, under the name of *Echinosphærites malum*. It is an excellent and easily-recognised genus, well marked by both habit and structure. The body is built up of four series of plates; the pelvic or basal series consist of four plates, of which two are pentagonal and narrow, and two hexagonal and broad, an arrangement very different from that presented by any of the preceding genera. The second, or sub-ovarian series is composed of six plates, of which the largest is that most anteal on the left side. Of these plates three are more less heptagonal, one hexagonal, and two pentagonal. One of the pentagonal plates, and one of the hexagonal, correspond with respect to the ovarian aperture to plates 7 and 8 of *Echino-encrinus*. The third, or centro-lateral, series consists of five hexangular plates, and one heptagonal, in consequence of emargination to form an arch over the ovarian aperture. Three oblong and very narrow pentagonal plates are represented as forming the supra-ovarian series. The mouth is central, and, according to Von Buch, proboscidiform; the ovarian pyramid small and five-valved; there are no traces of arms or tentacles. The type is especially interesting, on account of its evident relations with *Caryocrinus*.

I provisionally refer to this genus the following fossils:—

1. *Hemicosmites? squamosus*, Forbes.

A hexagonal depressed oblong plate, the broader extremity with three nearly equal margins, of which one is terminal, the narrow extremity truncated, the two straight sides much longer than any of the other margins; whole plate concentrically striated, the striæ parallel with the margins; centre somewhat raised, oblong elevated papillæ radiat-

* Pl. f. 17 *a*, *b*.

ing from it, but rather irregularly. Length, $\frac{7}{25}$ of an inch; maximum breadth, $\frac{6}{25}$; distance of summit from end of broad extremity, $\frac{2}{25}$. The aspect of this fossil is remarkably scale-like. I believe it to be one of the plates of the supra-ovarian series of *Hemicosmites*. From the Bala beds.

2. *Hemicosmites pyriformis.*

Echinosphærites malum, Pander, Beitrage, t. xxix., f. 1 *a*.

The figures 2, 3, 4, and 5, of Plate 20., represent plates of Cystideans, common in the Lower Silurian (Llandilo) beds of Shole's Hook. Some, as No. 2, are pentagonal; others, as 3, 4, and 5, are hexagonal. To each angle runs a prominent ridge, the sides of which are tuberculated, and sometimes the ridges themselves; the interspaces are transversely grooved; the grooves, however, in many instances, being very obscure. The largest example is half-an-inch in length. They agree so well in sculpture and form with the plates of *Hemicosmites pyriformis*, that I do not hesitate to assign them to that species.

Some of the specimens of the fossil supposed by Mr. M^cCoy to be the scale of a fish, and named by him *Acanthalepis Jamesii* (collected by the Geological Surveyors from the Lower Silurian of Newtown, Waterford), so closely resemble the fossils just described, that I think they can scarcely be separated. The figures given by Mr. M^cCoy, however (Synopsis of the Silurian Fossils of Ireland, Plate 1, f. 1 and 2), appears more nearly to resemble the distorted ovarian pyramid of a *Sphæronites*.

3. *Hemicosmites? oblongus.*

Echinosphærites oblongus, Pander, Beitrage, t. xi., f. 22, 23?

With considerable doubts, I refer a fossil from the Lower Silurian (Llandilo) beds of Shole's Hook, to the figure just quoted from Pander and Von Buch to *Hemicosmites*. The fossil in question exhibits plates, which are marked with fasciculi of radiating grooves, in the manner of *Caryocystites granatum*, of which it is just possible that it may be a distortion. The small number of plates, however, and their apparent arrangement, would lead rather to the inference that they belonged to *Hemicosmites*.

Caryocystites, Von Buch.

This genus was founded for armless Cystideans, having no pectinated rhombs upon their sides, and whose bodies were covered with numerous plates, but not so numerous as to prevent the recognition of a definite order and number in their arrangement. Von Buch combined in it three species, which have a pelvis formed of four basal plates, two of

which are large and two small, and sides protected by three successive ranges of lateral plates.

The British fossils which seem referrible to this genus, though often beautifully preserved in part, are rarely sufficiently so throughout as to enable us to recognize the relative position of all the plates, and the arrangements of the mouth, ovarian opening, and base, in any one specimen. The fragmentary materials, however, are fortunately not scarce, and enough to furnish good evidence of the specific distinctness of a number of forms, though the evidence of the connexion of all of these with the genus *Caryocystites* is not quite so clear as might be wished. With the exception of the first species in the list, the descriptions given must be regarded merely as provisional.

1. *Caryocystites granatum*, Wahlenberg.

SYNONYMS. — *Echinosphærites granatum*, Wahlenberg. Acta Soc. Ups. VIII. 53.; *Sphæronites testudinarius*, Hisinger, Lethæa Suecica, p. 92, t. 25, f. 9 *a.*; *Caryocystites granatum*, Von Buch, uber Cystideen, p. 17, t. 1, f. 8-10 and 2, f. 4. — Journal of Geological Society, vol. ii. pl. 3, f. 4.

The body of this species is sometimes nearly sphærical, sometimes oblong. The arrangement of the lateral plates is obscured by their peculiar and beautiful sculpture. The centre of each is slightly raised, and from it proceed six sets of radiating ridges and grooves, usually four of each in each ray. These unite and pass completely into the corresponding radiating ridges and grooves of the neighbouring plates, so that the whole surface of the body is covered with a complicated net-work of ridges and grooves. The breadth of each ray is such that the triangular interspaces between the reticulations are very small. The lateral plates vary in size in different specimens, but their usual diameter is about $\frac{2}{10}$ths of an inch.

Among the collections made by Mr. Flanagan, of the Irish Geological Survey, during the autumn of 1847, are several specimens of this species from the limestone of the Chair of Kildare. One of these shows the arrangement of the plates better than any of our Welsh examples. The basal plates in the Irish specimens are four in number; the two largest hexagonal, the two smaller pentagonal. They form a cup-shaped pelvis, and are almost smooth, or present indications of the radiated groovings only upon the upper part. They are surmounted by three circles of six hexagonal laterals, all of them radiately ridged as before described. These are crowned by a series of elongated oral plates, six in number, and smooth, except some traces of radiated ridges towards their bases. The ovarian opening is rather small, and

so placed that a series of ridges, passing in a straight line through the centres or bosses of two lateral plates, conduct to it.

The largest entire specimen which I have seen of this species, measures an inch in height; it is from the Bala limestone, at Reulas. The species also occurs at Shole's Hook, and, as I have before noticed, in the silurian limestones of the Chair of Kildare, in Ireland, where its presence, in company with other cystideans, likewise found in the lower Llandilo beds of Wales and certain trilobites, especially *Illænus Bowmanni*, and molluscs, also Bala species, has furnished an important datum towards the identification, which I have proposed, of the Irish Silurian beds in question with the Bala limestones and associated rocks. As there are, moreover, good grounds for the identification of the Chair of Kildare limestones with those of Courtown, in Wexford, the position of which in the series of silurians of the east of Ireland is clearly made out, we thus get a geological horizon for an accurate comparison of the Irish with the Welsh silurians, and for the recognition of equivalent beds.

2. *Caryocystites Davisii*, McCoy.

In a communication respecting the specimens of Cystideæ contained in the Woodwardian Museum at Cambridge, kindly furnished by Mr. McCoy, that gentleman has drawn up an account of a new species of Caryocystites from the Lower Silurian (Llandilo) beds of North Wales, where it was found by Mr. Davis.

Mr. McCoy describes this specimen as follows:—"Sp. Ch. Sphæroidal, diameter about seven lines; lateral plates slightly convex, about two lines wide; from the centre of each plate a pair of close, equal, strong ridges extends directly to the centre of each of the adjoining ones; each pair of ridges passing through the middle of one of the straight sides of the plates, giving a six-rayed appearance of the hexagonal, and a five-rayed to the pentagonal ones, the intervening triangles being smooth, or nearly so. In the beautiful simplicity of its ridging, this species much resembles the *Echinosphærites Balticus*, but the large size of the plates, in proportion to the diameter of the body and their consequent small number, precludes the possibility of its being confounded with any species of *Echinosphærites* or *Heliocrinites*. On the other hand, on a comparison with a fine suite of *Caryocystites granatum*, in Professor Sedgewick's collection from Oeland, their close affinity is obvious, while, as a species, the present fossil is readily distinguished by wanting the complex series of five or six converging sets of ridges, which in that form fill up the triangles intervening between the primary ridges, extending from centre to centre of the adjacent plates."

There are several specimens of this elegant cystidean in the collections of the Geological Survey. Though their general aspect strikingly resembles that of small specimens of *Sphæronites Balticus*, their structure would lead us to refer them, as Mr. M^c^Coy has done, to the genus *Caryocystites*. Indeed, it is just possible that they are extreme varieties of *C. granatum*, for the size of the plates in that species, and the arrangement of the ridges on undoubted examples, is not so constant as to induce us to lay great stress on those characters in the present state of our knowledge. Nevertheless, as the form is one easily recognizable, and probably geologically important, I have great pleasure in adopting the name proposed by my friend, Mr. M^c^Coy; the more so, as it is given in honour of a most ardent and active geologist, who has done much towards the investigation of his native country.

Caryocystites Litchi, Forbes.

Among the more obscure, but not uncommon, forms of Cystideans which have been discovered by the collectors of the survey in the Lower Silurians of Bala and Shole's Hook, in Wales, one of the most remarkable is a globular species, to which on account of its shape, and the peculiar sculpture of its surface, I have given the name of *Caryocystites Litchi*, in allusion to the tropical fruit so called. The external surface is nearly smooth, and free from radiating ridges, but marked over the greater part by minute pores, arranged in pairs, and connected together by a space, which is bounded by an oblong groove (Pl. 21, f. 2 *e*); these connected pores have a somewhat regular and spiral arrangement. One specimen (Pl. 21, f. 2 *c*) shows that each pair of pores was placed in the middle of a small six-sided space, such spaces being placed together exactly as if they were so many small plates, for which they might easily be mistaken. That this appearance is deceptive, is seen when the test of the body is removed, for then the impressions of the sutures of full-sided plates upon the nucleus show that the entire body was, in all probability, a *Caryocystites* (pl. 21, f. 2 *b*). This is further borne out by the form of the summit, which exhibits two pap-like projections for the oral and anal orifices, exactly as in *Caryocystites testudinarius* (Von Buch, uber Cystideen, plate 1, f. 20). Traces of the ovarian aperture are seen on the upper half of the body, not far below the mouth, and in the most usual position with respect to the vent. The usual diameter of the specimens is about one inch, or a little more. The singular sculpture of the surface is unlike any as yet described or figured from this group, though it is possible that the peculiar markings of the body, figured by Schlotheim (in the Isis for 1826), under the name of *Echinosphærites alcyonium,* may be of the same nature.

Caryocystites pyriformis, Forbes.

Allied to the last in the presence of peculiar twin pores, though not furnished with the plate-like hexagons in the midst of which they are placed, is a fossil frequent in the Reulas limestone, and not uncommon in that of the Chair of Kildare. It is constantly elongated, in that respect reminding us of the foreign *C. testudinarius*, the base forming a cone, gradually expanding upwards; the broadest part of the body being about the middle. The oral and anal orifices are placed on the summit, and the ovarian pyramid, the plates of which have been preserved in one specimen (pl. 21, f. 1 *b*), is placed a little way beneath them. The surface appears smooth, except where marked by twin pores, somewhat irregularly scattered. Each pair of pores is placed in a broadly oval space, but these spaces, or rather minute ridges, connecting the pores, vary considerable in form. The arrangement of the plates composing the body has not been distinctly exposed in any specimen as yet discovered. About $\frac{3}{4}$ths of an inch in length is the usual size of specimens, but no one has been found quite complete.

Caryocystites? munitus, Forbes.

Two specimens of a minute Cystidean have been found in the Bala limestone, at Reulas, which, though the number of plates, so far as can be made out, is too few for the genus, their structure and the presence of minute twin pores on their surfaces, indicate so close an affinity with the two species last described, that I provisionally placed them in sequence. They are both globular bodies, nearly smooth, except for the markings referred to, and are especially distinguished by their summits being crowned with four tubercles, connected together by ridges, so as to form, as it were, a turreted wall and square fortification around the mouth. The ovarian orifice, of which the valves are indicated in one of the specimens found, is placed immediately below one of the walls of the square. This species is probably the young form of some larger cystidean not yet found. If so, it would indicate that the number of plates in Caryocystites increases with age.

SPHÆRONITES (Hisinger), or ECHINO-SPHÆRITES (Wahlemberg).

The *Sphæronites* are armless Cystideans, strikingly distinguished from all others by the great number and irregular disposition of the plates which cover their bodies. They are more or less sphærical, borne upon a stalk (which in British examples has never been seen, either free or attached), described as thin, round, and furnished with a pentagonal canal. At the inferior pole a pelvis is seen composed of six basal plates, and at the superior, two orifices, one very small, the other con-

spicuous; the latter being the mouth, the former the anus. On the postero-lateral portion of the upper hemisphere of the body, in a line with the mouth, is seen the ovarian pyramid, composed of five triangular valves, firmly articulated together, or even anchylosed, and having perforated summits. The plates which compose the remainder of the body are polygonal and variously ornamented with punctations, striæ, or ridges. The striæ and ridges always radiate from the centre of one plate, to pass continuously into those radiating from the centre of the surrounding plates, so as to present the figures of lozenges and stars; the centre of each star being the centre of a plate. The result of this arrangement is to conceal the sutures of the plates, and render the observation of them difficult; but when their position with respect to the centres is understood, it becomes easy to trace their points or lines of union.

The *Sphæronites* were the first Cystideans that attracted notice, having been described by Tilas and others, before the middle of the last century, but with a complete misapprehension of their nature, for instead of being recognised as animals, they were supposed to be mineral bodies, a false notion in which Linnæus himself participated. Gyllenhal (in 1772) was the first who distinguished their animal nature, and perceived that they had relations with *Echinus*, with which genus he placed them. Wahlemberg, fifty years afterwards, revised this view, and placed them intermediate between the Sea-urchins and Crinoids.

With the exception of the body called by Phillips *Sphæronites tessellatus*, a remarkable Devonian fossil, the true zoological position of which is doubtful, the species of *Sphæronites* are characteristically Lower Silurian. They have been found in Sweden, Russia, and Bohemia. M. De Barrande has recently discovered strata almost entirely composed of them in the last-named country. In the British islands the first Silurian Sphæronites made known was that described by Mr. M^cCoy, under the name of *Echino-sphærites granulatus,** discovered by Mr. Griffith, in Wexford; unpublished fossils of this genus had, however, already been collected and examined by the officers of the Geological Survey of Great Britain, who had discovered numerous remains of them in the Lower Silurian rocks of South Wales.†

1. *Sphæronites aurantium.*

PRINCIPAL SYNONYMS.—*Echinus aurantium*, Gyllenhal; *Echino-sphærites aurantium,* Wahlemberg; *Leucopthalmus Strangwaysii*, König., (Icon. Sect. pl. 1, f. 1.); *Sphæronites citrus*, Hisinger;

* Synopsis of the Silurian Rocks of Ireland, p. 59, pl. IV., f. 16.

† See list in Part I. of this volume, p. 30.

Sphæronites aurantium, Von Buch, Eichwald, Count von Leuchtenberg; *Echino-sphærites aurantium*, Pander, Volborth, De Verneuil.

Body sphærical or oval, covered by very numerous small polygonal plates (according to De Verneuil, 150 to 200), mostly hexagonal, but not unfrequently very irregular in form (according to Von Buch, at least 20 upwards in a row). Plates seldom exceeding $\frac{1}{8}$th of an inch in diameter, marked with fasciculi of radiating striæ, stellately arranged over the surface of the body. Base composed of six small wedge-shaped plates, forming an inverted cone. Ovarian pyramid depressed, formed of five, rarely six, closely-articulated, triangular, smooth, marginated plates, with perforated summits. "On the top of each of these valves," says Von Buch, "is a small orifice piercing quite through the valve, and possibly the eggs are extruded from these orifices, since the valves themselves are never found open. In a direct line between the mouth and this little pyramid, but quite close to the mouth, is a small round anal opening, not quite elevated to the surface." The latter opening in the specimens, both British and foreign, which I have examined, is not exactly between the ovarian pyramid and the mouth, but placed on the left side, and a little behind the latter. It is always small as compared with the mouth. The oral orifice seems to have been protected by a special series of plates, arranged so as to form a pyramid or proboscis-like organ. It is always placed at the opposite pole to the point of insertion of the stem.

The cast of the interior of this species presents no traces of the radiating striæ, but exhibits raised lines, indicating the divisions of the plates, and raised papillæ, indicating pores or punctations of their inner surfaces. Such papillæ are also seen on the surface of the nucleus of the ovarian pyramid. When the plates are preserved, they are frequently so worn upon their outer surfaces as to present few or no traces of the radiating striæ, and their punctations become conspicuous, corresponding to the papillæ seen upon the casts of their inner faces.

Our British specimens of this fossil, though by no means scarce, are almost always very bad. None have as yet been found in a state comparable with those brought from the north of Europe. It occurs plentifully in parts of the Bala limestone (as at Reulas), and in the shales of Shole's Hook.

The Irish *Echino-sphærites granulatus*, from beds of corresponding age in Wexford (Carrickadaggan, near New Ross), approaches so very closely to this form, that I doubt the propriety of separaitng them. In describing it, Mr. M^cCoy had the disadvantage of examining internal casts only.

2. *Sphæronites arachnoideus.*

In the lower Silurian (Llandilo) beds of Shole's Hook and Bala are badly-preserved specimens of a Sphæronite, having much larger plates than the preceding species, and ornamented with radiating striæ, much more conspicuous and more numerous, though similarly arranged. The casts of the interior show much larger punctations; the ovarian plate appears to have been similar. I have no doubt that this is a distinct species, though as yet we have not got materials for a fuller description. In the mean time I name it provisionally as above.

3. *Sphæronites balticus.* Eichwald.

Principal Synonyms.—*Echino-sphærites*, Schlotheim. [In Isis for 1826, p. 314, pl. 1, fig. 7.]

Echino-sphærites balticus, Eichwald. [In Zool. Spec., vol. i. p. 231, pl. 3, fig. 12.]

Heliocrinites balticus, Eichwald. [In Sil. Syst. Esthl. and Urwelt's Russ.]

Echino-sphærites aranea, Volborth. [Loc. cit. Pl. IX. figs. 2, 3.]

Echino-sphærites balticus, De Verneuil. [In Geology of Russia, vol. ii. p. 25, pl. 1, fig. 9.]

Body round or oblong, covered with polygonal plates, larger than those in *Sphæronites aurantium*, and conspicuously ornamented with radiating ridges, the rays very prominent. Six of these ridges are present on most of the plates, and, proceeding to unite with the ridges on the neighbouring plates, the whole surface becomes covered with a network of triangles, and a complication of star-like devices, so as completely to conceal the true disposition of the plates.

The number of plates in young specimens of this species is much fewer than in full-grown examples, so that it is not improbable that the fossil described under the name of *Caryocystites Davisii* may be an immature *Sphæronites balticus.*

The *S. balticus* occurs in Lower Silurian beds (Llandilo) at both Shole's Hook and Bala.

4. *Sphæronites ? punctatus.*

I have given this name provisionally to certain Cystideans which occur plentifully in the Bala beds, especially in the Reulas limestone, but which are in too imperfect a state to determine more than their distinctness from the several preceding species. In form and size they resemble *S. aurantium*, but the surface, which at first glance appears nearly smooth or slightly pitted, is seen, on closer examination, to be covered by minute rugosities, presenting a very obscure radiated arrangement. Better specimens will be required before the relations of this form can be determined with certainty.

Agelacrinites.

One of the most remarkable Cystideans as yet discovered in British strata is a fossil which rewarded the exertions of the collectors for the Survey in North Wales during the summer of 1847. It is a hemisphærical, many-plated, sphæronite-like body, but presenting the striking characteristic of possessing five serpentine grooves, radiating from its mouth, and occupied by as many appressed arms. Within one of the compartments formed by the surrounding arms is an ovarian pyramid. Thus it exhibits characters which in some degree link the very different types, *Pseudocrinites* and *Sphæronites*.

Although no similar European form had been described by any author, its aspect immediately called to mind a remarkable American fossil, figured and described by Mr. G. B. Sowerby, in the second volume of the Zoological Journal.* The body in question was discovered by Dr. Bigsby, in Canada, and Mr. Sowerby describes it as follows: —

"Upon examination of this fossil, we do not immediately recognise its affinities, for it bears so near a resemblance to the arms of an Asterias lying on an Echinus; we think, however, judging from the want of ambulacra, that it would be properly placed among the genera of the *Asteriadæ*. At the same time its vicinity in general form to Say's family of *Blastoidea*, renders it doubtful whether it ought not to be considered as a connecting link to be placed between the two families of *Crinoidea* and *Blastoidea*, and this suggestion obtains support from the apparently lateral situation of the mouth, in which respect it resembles some of the *Crinoidea*. This suggestion, however, involves the following consideration, namely, whether those rays in the *Blastoidea*, which, by Say, are called *ambulacra* (a term commonly applied to an apparently corresponding part in the Echinida), really serve the same purpose, or whether they be not arms, as in the other *Crinoidea*. And I venture to assert that there is nothing either in their position or form that militates against such an idea.

"I hope the following description, together with the figure by which it will be accompanied, will serve to give as correct an idea of the fossil in question as can be conveyed without the actual examination of the specimen.

"The general form, as far as we can judge from the specimen, in which none of the lower part is preserved, is a depressed spheroid, and it does not appear to have naturally any angular prominences, though, owing to the circumstance of its being divided into five sections, it might possibly be very obtusely pentagonal. It appears to have consisted of a number of irregular, partly imbricated, crustaceous plates, and its upper half is divided into five sections or compartments, by five equal arms, which diverge from the centre, and are curved all in the same direction.

* Zoological Journal, vol. ii., p. 318, pl. 2, fig. 5.

"The compartments are not equal in size; in the largest of them, and near its centre, is placed the *mouth*, which appears to have been surrounded by two or three rows of very minute, imbricated, crustaceous scales; the arms, five in number, all diminishing to a point at their outer extremity, and having their upper portion elevated above the body, seem, however, to be attached to it by their under side, and, indeed, partly bedded in it; each one is divided into two equal parts by a longitudinal groove, and each of these parts is again divided into a number of segments by transverse and deep grooves, which are close set, being about half their length distant from each other. I cannot ascertain whether there is any natural opening in the centre or not. The whole is changed into crystalline carbonate of lime, coloured by iron rust, and it lies upon a mass of limestone, containing a mass of Encrini and Madreporites; a single spiral univalve is also to be observed. From the Falls of the Chaudière on the Ottawa River in Lower Canada."

Although the true affinities of this curious fossil are not recognised in this description, and many of the parts misinterpreted (as, for example, the ovarian pyramid is regarded as the mouth), still there can be no question, especially when the very characteristic figure which accompanies the paper is examined, of its true position being among the Cystideans, and of its being generically allied to the British fossil we are about to describe.

A second American congeneric form is described and figured in Vanuxem's Geological Report on New York (p. 168), under the name of *Agelacrinites Hamiltonensis*:—

"At the upper quarry I found a fragment of the external impression of a singular and beautifully-wrought crinoidal fossil, the most so of any hitherto seen in the system, and unique as to kind. A cast of it shows a connected surface, upon which six detached circular forms were placed, having the appearance of medallions, their whole surface and sides, which are inclined, being highly wrought with minute markings, like Gothic tracery. Three were of the same size, rather over an inch in diameter, slightly ovoid, and clustered together. One only was entire, the two others having been broken off, but leaving sufficient to show their size and character. The other three were small, two being nearly equal, and each less than the fifth of an inch in diameter, the third double that diameter, and all three were placed together in an angle formed by two of the larger ones. Near the centre of the largest and perfect medallion are five branching arms, like those of an asterias, or star-fish, between two of which, and those which are most expanded, is a star, which probably was the mouth of the animal. As this is the first instance in which distinct crinoids have been found clustered together so as to form one system, it therefore establishes a new genus, for which the name *Agelacrinites* is proposed, from agele, a herd or group, and *Hamiltonensis* for the species; in common language, the Hamilton agelacrinite."

The *Agelacrinites* are very important fossils in their bearing upon the

nature and characters of Cystideans, and of other bodies apparently related to them. Like *Pseudocrinites*, they show that the presence of arms is quite consistent with that of an ovarian pyramid. They show further, that there is no correspondence between the presence of pectinated rhombs or of a small number of plates, and that of arms. They prove a direct relation between *Pseudocrinites* and *Sphæronites*, for the structure of their plates is essentially that of the latter type, whilst the arms and arm-canals link them with the former. The peculiar structure of the apparently membranous base indicates an analogy with that anomalous fossil, the *Ischadites*, and suggests the possibility of its eventually proving to be a naked and coriaceous cystidean, allied to *Sphæronites*. The characters of the stems, which appear to belong to *Agelacrinites*, if really so, indicate their relation to crinoids, and render it probable that many of the so-called encrinite rings in the Lower Silurian rocks may eventually prove to belong to the stems of Cystidiæ. The general structure of *Agelacrinites* proves that the *Sphæronites* had no true arms, for here, where they are present, as in *Pseudocrinites* and *Pentremites*, there are peculiar grooves formed to receive the arms; but no such arrangement can be observed in *Sphæronites*, or the allied genera. I have stated that we have no pectinated rhombs present in this genus. A question might arise, especially as there are no traces of such bodies in *Pentremites* as well, whether, when the arms are developed in their full and normal radiate numbers of five, pectinated lozenges are ever present? It is more probable, however, bearing in mind the view we have taken of the nature of those curious bodies, that their presence or absence has no relation with the number of the brachial appendages. One important point is strongly suggested by the structure of the arms and arm-grooves in this curious genus, viz., that it is possible the ambulacral avenues of all Echinidæ are embodied arms, when embodied usually separated by ambulacral plates; that here we have the latter, but no avenues, for the arms themselves are the avenues freed from the body; consequently that the anomalous genus, *Palæchinus* (and perhaps *Archæocidaris* also) is an intermediate form between *Agelacrinites* and true urchins—an abnormal *Agelacrinites*, so to speak, in which the arms have become embodied.

Agelacrinites Buchianus, Forbes.

Body hemisphæric, slightly depressed above, with a concave base, the margins of which are rounded. The mouth appears to have been in the centre of the summit, and from it radiate deep canals or grooves, five in number, regularly bordered by close parallel ridges and sulcations. These canals (in which the arms are lodged) are each and all curved

in one direction, so that their apices approach in a spiral or slanting fashion around the base and on its margins. In the widest of the five interspaces the projection which bore the anus is seen, following the mouth, and in the centre of the upper half of the same compartment, is a circle, with radiating markings, converging to a central point. This indicates the position of the ovarian pyramid. Round this numerous plates are seen, variously polygonal; those on the left side largest; those on the right most numerous. The interspace, side or compartment between each pair of arms, is of an obliquely pyriform or petaloid shape, in consequence of the curve of the arm-canals, and their approximation towards their extremities. The greatest breadth of this space is occupied in four of the areas by about five polygonal plates; in that which includes the ovarian pyramid by four. The two plates above the ovarian area join by a suture which runs straight towards the mouth. The margin of the arm-canals are constructed out of areal or inter-ambulacral plates, bearing 2-3 short elevated transverse ridges, each of which points to the origin of an ambulacral plate, short and oblong; a double series of these ambulacral plates form the canal.

The valves or sides of the ovarian pyramid are gone, but the impressions of their sutures indicate that there were five of them.

The plates of the areas extend round the margin of the base, but not to its centre. In the unique specimen examined, they go but a little way over the edge; but on one side there are indications of their having originally proceeded much farther and near to the centre. The centre of the base is occupied and surrounded by five prominences, outside of which, all round, there is a space finely, reticularly, and as if squamously, crisped, apparently the impression of a tough membrance. From the centre, over and on the membrane, radiating lines, with the appearance of having been caused by vessels, proceed, dividing in their course. The impression of the base shows its structure still better. The markings of the basal membrane are very distinct, and resemble those of *Ischadites*. The plates immediately bordering it are rather larger than the others, and all the plates of the base are marked with twin pore-like dots, connected by a groove. The membrane appears to project in 11 points; the odd one corresponding to the ovarian area. With the specimen described was found the impression of the base probably of a similar cystidean, showing a quadrangular centre (opening of canal of the stem?), and four oval impressed spaces with raised centres, each having a radiating bordering space.

The arms were triangular, so as to fit into the grooves, and their upper and outer surfaces appear to have been channeled. They were composed of two rows of dove-tailing joints, with ridges at the articulations to lock into the furrows bordering the arm canal.

Along with the specimen were found several fragments of a cylindrical thick stem, composed of joints which, in some portions, are very thin, in others, moderately thick. Externally, it is smooth, or nearly so. The canal is of small dimensions. The articular surfaces of the joints are radiated. I believe this stem to have been, in all probability, the stem of *Agelacrinites*. It is figured in the same plate.

The dimensions of our specimen were as follows :—

Breadth, $1\frac{3}{8}$ inch.
Height, $\frac{5}{8}$ inch.
Breadth of ovarian compartment, $\frac{2}{8}$ inch.
Greatest distance between the arms, $\frac{6}{8}$ inch.
Distance between their apices, $\frac{6}{8}$ inch.
Distance of ovarian pyramid from mouth, $\frac{3}{8}$ inch.
Length of arm, $\frac{7}{8}$ inch.
Number of articulations, about 50 in each arm.
Breadth of arm, $\frac{3}{25}$ inch.

The only specimen procured was found by Mr. Gibbs (of the Geological Survey), near Yspetty-Evan, in North Wales, in a mass of schistose rock, from a quarry in beds associated with the Bala Limestone.

SECT. III.—ON THE POSITION OF THE CYSTIDEÆ IN THE ANIMAL SERIES.

There has been much difference of opinion among naturalists respecting the true zoological position of the *Cystideæ*. Even the great class or type within which they should be ranked has not been agreed upon by all ; for some have regarded them as Mollusca, others as Echinoderms. It is necessary, before offering an opinion on this subject, briefly to mention the several views which have been taken of their nature.

1. *Minerals.*—The notion that they were mineral bodies, presenting peculiarities dependent on crystallization, was entertained by Linnæus, and was suggested by the peculiar appearances presented by the Swedish examples of *Sphæronites*, depending on changes which have taken place during the mineralization of these curious fossils. Had the great naturalist of the north met with well-preserved specimens, and, above all, had he seen examples of the armed forms of the *Cystideæ*, we cannot doubt that his sagacity and knowledge would have conducted him to a view of their affinities much nearer the truth.

2. *Echinidæ.*—The opinion offered by Gyllenhal in 1772, that they were sea-urchins, comes next in order of time ; and, considering that

it was the first view offered of their animal nature, was remarkably near the right one. In 1830, Pander put forward the notion that they were pedunculated sea-urchins, "even as Crinoids are pedunculated Euryales." But Crinoids are not pedunculated Euryales any more than the latter are pedunculated Ophiuræ.

3. *Animals intermediate between Sea-Urchins and Crinoids.*—This view of their position—one which I shall have presently fully to consider—was suggested by Wahlenberg in 1821.

4. *A distinct order of Echinodermata inferior to Crinoids.*—This very important view of their nature originated with Von Buch, and has been followed by De Verneuil. Of all the opinions mentioned, this, though probably not so correct as that entertained by Wahlenberg, was the only one fairly founded on natural history reasoning, and offered as the result of a careful induction. The essay in which it was proposed is a model for palæontological monographs, full of earnest consideration and appreciation of minute detail, and equally full of high philosophical thought and suggestiveness. Every sentence shows how deeply Von Buch has pondered over the great problem of the material manifestations of life.

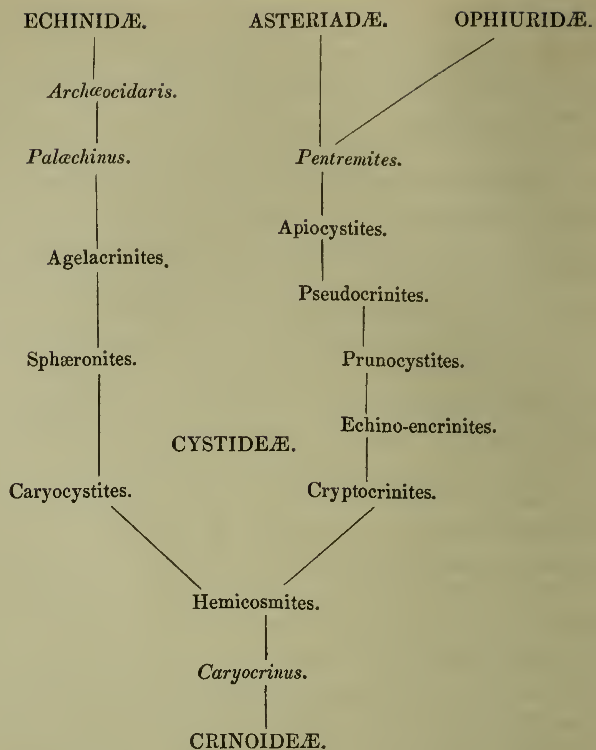
5. *Crinoids.*—This view has been ably maintained by Volborth, and is taken by several systematic authors with equal consideration. Professor Pictet, in his excellent "Traité elementaire de Paléontologie," divides the Crinoids into three sub-families, of which the first consists of the "free Crinoids" (*Comatula*, *Marsupites*, &c.); the second, "armless Crinoids;" and the third, of "armed or true Crinoids." This second sub-family he divides into three tribes, viz., "Echinocrinides" (*Echino-crinus*, *Ichthyo-crinus*); "Astro-crinides" (*Pentremites, Nucleo-crinus, Orbitremites*); and "Cystidies." *Caryo-crinus* he regards as the type of the first tribe of the true Crinoids. I notice this classification, because, in several respects, it is a great advance upon previous arrangements; and the relative position of his armless and armed Crinoids, and of the tribes of the former, is that most according with the view argued in this essay. But, in the extreme separation of the free from the armed Crinoids, a great error seems to me to be committed; for assuredly all we know of *Comatula* indicates its close relationship to *Pentacrinus*, in the absolute condition of which genus it passes a considerable part of its existence.

6. *Ascidian Mollusca.*—This view was put forward by M. König in his "Icones-sectiles," and has been, so far as *Sphæronites* is concerned, supported by Mr. M'Coy, in his account of Mr. Griffith's collection of the Silurian fossils of Ireland. In that work the Irish species of the genus (*Echino-sphærites granulatus,* Mr. M'Coy), is placed under the

Echinodermata; but in a note which I extract below,* the describer ingeniously compares the genus to which it belongs with a very extraordinary Ascidian described by Mr. Broderip and Mr. Sowerby, under the name of *Chelyosoma.* The condition of the viscera in the specimens examined of this curious creature was so bad, that its true affinities may be regarded as doubtful. Other *Ascidiæ* exist, covered with regularly arranged polygonal plates. In the "History of British Mollusca," by myself and Mr. Hanley, I have described and figured a beautiful species of *Cynthia*, the surface of which is covered with polygonal plates, so as to bear a striking resemblance to the test of an Ascidian. But these I regard only as resemblances of analogy, for as, besides the anal and branchial openings in the Ascidiæ, there is no special reproductive opening, the additional and complicated orifice of the generative system in the Cystideæ is of itself a sufficient proof that those creatures were not Tunicata. And the affinities of *Sphæronites* are too evidently connected with the others, and more crinoidal forms of Cystideans, to permit us to think that the tribe as defined by Von Buch includes animals of more classes than one. It is possible, however, that the fossil called *Ischadites*, which, in some respects, resembles a Cystidean, was an *Ascidian.*

After a careful study of the species described in this memoir, I am induced to maintain a view partly suggested by Wahlenberg, viz., that they are intermediate between the Crinoids and higher Echinoderms; that they conduct us from the Crinoids to the Sea-urchins and Starfishes. I have constructed the following diagram, graphically to express the sequence of their affinities:—

* "Although in deference to Baron von Buch and other palæontologists, I have arranged *Echino-sphærites* under the Echinodermata, yet it may not be amiss to state that my own impression of its affinities approximates more to Mr. König's original view. I would, however, differ as to the genus and recent form, to which I should refer for a close comparison of characters, as I conceive that it is to Mr. Broderip's genus *Chelyosoma* (see Zool. Jour., vol. v.) that the *Echino-sphærites* are most allied. This remarkable animal is almost generically identical with the fossil before us; it is a tunicate mollusc, enclosed in a tough coriaceous cup; the upper surface covered with distinct, horny, polygonal plates; the lower leathery portion also showing a tendency to assume an imperfect or irregular plated structure; the upper surface exhibits also two conical valvular openings, perfectly corresponding with the oral and ovarian openings which I have figured in the *E. granulatus*, except that they are composed of six plates each in the recent animal, and of only five in the fossil. It seems to me that the irregular division of the integument which I have observed constantly, and figured in the *E. granulatus*, indicates a coriaceous, imperfectly divided covering, like that of Chelyosoma, rather than the definitely angular regular plating of the crust of the Echinodermata. The recent animal alluded to adheres to stones, &c., by short processes of integument, like the pedicles of *Echino-sphærites*. It will be observed that the species I have above described approaches much more nearly to the type I have alluded to, and departs more from the echinodermatous types, than any of the species previously known."



This I shall now proceed to explain.

The value of the true Crinoids, as a great order of Echinoderms, cannot be doubted by any thoughtful student of the Radiata. The difference between the arrangements of their reproductive system, and that of the other orders of *Echinodermata*, of which we have living examples, is too great and typical to permit of their being confounded. Even those zoologists who were ignorant or neglectful of the study of fossil forms, without which no man can be a naturalist, properly so called, never confounded the *Comatulæ*, few as they were, with the *Ophiuræ*, but always regarded them as members of distinct groups,—groups, too, evidently far apart. The inclusion of the reproductive glands within the disks of the *Ophiuræ* and *Echinidæ*, and within their lobed prolongations over the produced arms of the *Asteriadæ*, presented a character so important and conspicuous as contrasted with the disposition of the generative organs diffused over the arms and pinnules of the Crinoids still existing, that their ordinal separation in any system pretending to a natural analysis of affinities was inevitable. When Von Buch brought his extensive zoological knowledge to bear upon the

structure of *Sphæronites* and its allies, he saw at once that, for reasons equally strong, they deserved to be separated from the Crinoids to which they bore most resemblance, and from all other known orders of *Echinodermata* as well, and accordingly constituted them as a distinct group, under the happy designation of *Cystideæ*, a view which, it seems to me, cannot be reasonably disputed. Consequently, in the preceding diagram, I have adopted an uniform type for the names of the groups *Echinidæ*, *Ophiuridæ*, *Asteriadæ*, *Cystideæ*, and *Crinoideæ*, indicative of their equal value.

In the diagram, the word CYSTIDEÆ occupies the centre, and around it are the names of the several genera of undoubted Cystideans, printed in small roman letters, and arranged in the order of their affinities. Between them, however, and the names in roman capitals, indicating the great groups of equal value with the CYSTIDEÆ, are other names of genera printed in small italics. These are the genera which seem to me to link the Cystideans with the members of the other great sections of *Echinodermata*. The lowest of these is the remarkable fossil *Caryocrinus*, admitted, on all hands, to afford a distinct passage from the Crinoids to the Cystideans, as far as there can be a distinct passage between two great orders. The affinity of this singular genus with the Cystideans has been so fully demonstrated by Von Buch, that it need not be discussed here: the position he assigns to it as a genus in the lowest rank of Crinoids conducting to a lower order, though the opposite of that assigned to it in my diagram, where it is represented as a genus of higher rank conducting to a higher order, does not affect the demonstration of the proximate affinities of the two orders. The resemblances between *Caryocrinus* and *Hemicosmites* have also been sufficiently shown by Von Buch.

From *Hemicosmites* we advance onwards, and, as I believe, upwards, in two directions, the first steps in the march being taken by *Caryocystites* on the one hand and *Cryptocrinites* on the other; *Caryocystites granatum* and *Cryptocrinites cerasus* (a Russian fossil), may be cited in illustration. The progression from *Cryptocrinites* onwards, through *Echino-encrinites* to the armed and rhombiferous genera; and of *Caryocystites*, through *Sphæronites*, and other Cystideans without rhombs to the armed genus *Agelacrinites*, is obviously parallel, and the limbs are sufficiently close to prevent any doubts of the continuity of the chain. It is now, however, that we have to determine the direction of these parallel series; whether their course is from the Crinoids (where we have, as it were, found their root), upwards to the higher Echinodermata, and downwards to the *Zoophytes* and *Amorphozoa*. Von Buch, pronounced for the latter course, and argued his position fairly and well. The analogy he cited of the rudi-

mentary condition of the Comatulæ, as first made known by J. V. Thompson, was so striking and captivating as to convince all who thought well over his essay. I for one assented, until fresh evidence came to hand, which had not been before Von Buch at the time of the composition of his memoir. I allude to the undoubted affinity proved to exist between the *Pseudocrinites* and ordinary Cystideans, by the discovery of the peculiar *Echino-encrinites* of Walsall, and between the same extraordinary fossils and the *Sphæronites*, by the opportunity afforded for a careful examination of an *Agelacrinite* by the discovery of the first fossil of that wonderful genus in Europe during the researches of the Geological Survey in North Wales, in beds probably identical with those in which the first Silurian *Palæchinus* was discovered by Miss Phillips (see first part of this volume). Their discoveries at once suggested a new view of the affinities of the Cystideans. In the *Palæchinus* we had an *Agelacrinites* with its arms embodied; in the *Pseudocrinites*, a Pentremites with the peculiar reproductive pyramid of a *Sphæronites*. The close affinity of these genera became evident and indisputable, striking even to the unscientific observer. There remained only to determine the serial places of *Palæchinus* and *Pentremites*, before finally concluding with respect to that of the whole order of Cystideans.

Any zoologist who has seen the curious *Palæchini* of the carboniferous limestone of Ireland, most naturally united into a genus by Dr. Scouler, or who, not having the opportunity, examines the beautiful figures of those given by Mr. McCoy in his Synopsis of the carboniferous fossils of Ireland, must at once recognize in them aberrant forms of *Echinidæ*. This is the more manifest, seeing there can be no question respecting their affinity with the Palæozoic so-called species of *Cidaris*, constituting the excellent genus *Archæo-cidaris* of McCoy, nor on the other hand of that genus with *Cidaris* itself. Thus by *Agelacrinites* we are conducted through *Palæchinus* and *Archæocidaris* to ordinary sea-urchins.

We have seen that *Agelacrinites* is parallel with *Pseudocrinites*, which last genus is especially, through *Apiocystites*, allied with *Pentremites*. In such case the position of the last-named genus must be somewhere on a parallel with *Palæchinus*, and if so it must be, not between the Cystideans and Crinoids, or among the latter, but between the former and some higher order of Echinodermata. The absence of an ovarian pyramid is sufficient to show that the Pentremites are beyond the bounds of the Cystideæ.

During the spring of 1847, I was conducted by the Earl of Enniskillen to some mountain limestone beds near Florence Court, where he had found Pentremites in considerable numbers. I was anxious by

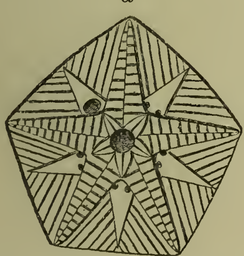
an examination of specimens *in situ* to ascertain whether I could so gain information respecting their structure and affinities more satisfactory than that furnished by published accounts. Fortunately finding them of all ages and in all states of weathering, specimens which would have been rejected as bad by mere cabinet collectors, afforded the desired information.

I found that of the five pores represented in figures as surrounding the mouth of the Pentremite in the angles between the arms, four are of a different nature from the fifth, being short cavities or arched cloaca, into each of which two smaller orifices open, whilst the fifth is a single orifice of greater dimensions. It immediately occurred to me that, in the former we had the genital openings arranged as in *Asterias* and *Ophiura*, and with one pair suppressed in consequence of the small pore, usually dorsal in the Asteriadæ, being brought round to the ventral surface in close proximity with the mouth as in *Echino-cyamus* and certain other genera of *Echinidæ*, in which order, especially in the allies of *Spatangus*, we find a similar abortion of one of the five single or double genital pores.

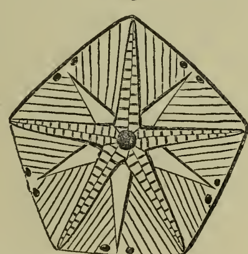
The analogy thus suggested, induced me to analyze the constitution of the exoskeleton of *Pentremites*, and to see whether it might not be reduced to the same plan with that of an Asteriad or Ophiurid.

I believe it can, as the following diagrams will explain :—

a



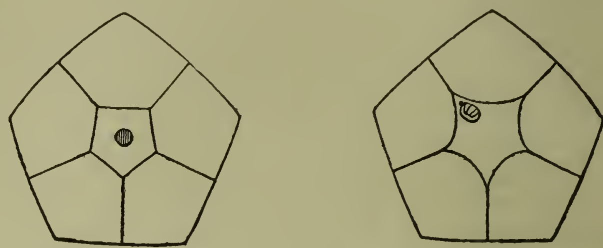
b



Let *a*, represent the projection of the arm-bearing surface of the *Pentremites pentagonalis*, and *b*, a similar projection of the ventral surface of the star-fish *Asteropsis pulvillus* (*Goniaster Templetoni* of W. Thompson), it is evident at a glance, that the ambulacra of the latter correspond to the arms of the former, and the disposition of the ossicula in the interbrachial spaces of the star-fish, to the arrangement of the striations in the corresponding parts of the Pentremite. The parts most different in position are the ovarian pores, which are arranged in pairs, marginally in the star-fish, but approximated to the mouth in the fossil, one pair being suppressed in the latter in consequence of the anal pore being brought near to the mouth, whereas in the star-fish it

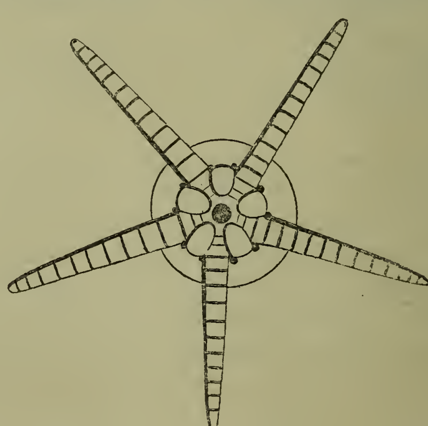
remains on the dorsal surface. Such changes in position of the reproductive and anal pores are continually occurring among the Echinidæ and Asteriadæ, and are in nowise astonishing to the zoologist familiar with Echinoderms.

c *d*



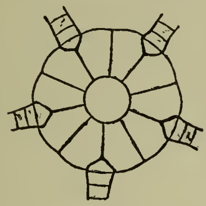
Let *c*, and *d*, in like manner, represent the dorsal projection of the same Pentremite and star-fish. It is evident that were the ossicula of the latter anchylosed into as many plates as comprise the former, we should have exactly the same arrangement of plates; the marked difference in the two cases being the lateral position of the madreporiform tubercle in the *Asteropsis*, as compared with the central position of the base of the Pentremite, with which I would compare it. Of course, in such a comparison, any notion of a near affinity between *Asteropsis* and *Pentremites* as genera, is out of the question, rendering the resemblance in the scheme of construction of each so much the more astonishing.

If we institute a similar comparison between the ideal projection of an Ophiura and that of a Pentremite, the resemblance of plan becomes even more striking, for, in the former type, the arms remain free. Thus, in the following diagram of the under surface of an *Ophiura*, we



have arrangements very similar to those presented by the fossil genus;

and if we suppose the twin plates at the bases of the arms in the upper surface of Ophiura, as in the accompanying cut, to be so developed as



to occupy all the disk with the exception of a central plate formed out of the anchylosed ossicula, the resemblance becomes equally striking to what may be called the cup part or dorsal surface of the Pentremite.

These comments on the structure of *Pentremites* are introduced only with a view to elucidate the zoological position of the Cystideæ; the working out of the *Pentremites* themselves, I propose to take up as a future task. It is enough at present to show that the Pentremite into which the Cystidean evidently, as it were, passes, in its turn becomes linked with the star-fish, even as the *Palæchinus* linked itself with the Cystidean on the one hand and the sea-urchin on the other. Grant the correctness of these inferences, and the position of the *Cystideæ* as an order above the Crinoids becomes a conclusion beyond doubt.

As long as we supposed the *Cystideæ* to be rudimentary or elementary forms of Crinoids, their prevalence in the lowest rocks of the palæozoic series served to indicate a sketching out in order of development of the *Crinoideæ* in time. We have already seen that many of the genera are strikingly characteristic of particular divisions of the Silurian series, but any notion of their being so, because they preceded the Crinoids in zoological series, must be abandoned, if the views and arguments which I have urged in this essay be admitted. Major Austin has lately stated that Cystideans exist even in our mountain limestone. I am fully prepared to admit the case to be possible; but specimens of the bodies which he has described as such, which I have had an opportunity of inspecting through the kindness of Mr. Morris, appear to me rather to belong to a group along with Pentremites than to true Cystideæ.

I shall conclude this account of our British Cystideans with an attempt at an abstract view of the position and affinities of the remarkable order to which they belong.

The Echinodermata first commence their existence as a class in the Crinoidea. Our knowledge of the metamorphosis of the Comatula, the

only crinoidal form of which the stages of development are known with certainty, shows that the individual crinoid, in this case, undergoes distinct metamorphoses representing, without question, known types inferior to the Crinoidea themselves, passing, in short, from the condition of an amorphozoon to that of a true zoophyte before it assumes its echinodermal state. Even in the latter it presents two distinct stages: the one, when it is a Phytocrinus, the stage beyond which the majority of fossil crinoids never advanced; and the other, when it is a Comatula, and approaches the Ophiura in its nature and habits.

The Crinoideæ, properly so called, are, as we have seen, succeeded in the series by the Cystideæ. But in this part of the ascent of the Echinodermal type, there is a perpetual struggle against the adverse influence of the negative or vegetative polar influence, manifested by the tendency of the genera to undergo a retrograde anamorphosis, and of the species to put on a pseudo-anamorphosis and crinoidal habit, often simulating the aspect of rudimentary Crinoids. Hence have some of our most philosophic and admirable naturalists, especially Von Buch, been induced, in the absence of evidence to the contrary, to regard these apparent retrogressions as indications of a very low serial position, and to place the Cystideæ below the Crinoids.

The great group of Echinodermata presents within itself a definite and unquestionable progression towards a higher type. This progression is manifested in the rapid anamorphosis of the generic forms or types included within it; so rapid that the extremes of the class, though linked by a nearly unbroken chain of successively proximate specific forms, bear not the slightest resemblance to each other (witness a Crinoid and an Echiurus), yet are they but modifications of one great type of organization. But extreme dissimilarity does not depend on their serial distance only, which is not sufficient to account for it. There can be only one cause for the difference, viz., polarity.

The two poles of being, the animal and the vegetable, manifest themselves respectively, in subordinate spheres by the tendency towards perfect individualization on the part of the first, towards combination and fusion on the part of the second. These tendencies are frequently accompanied by a manifest progression in the metamorphoses of the individual in the one case, and a retrogression as manifest in the other.

Now, among the Echinidæ, more conspicuously among the Holothuriadæ, and even yet more so among the Sipunculidæ, every step in the metamorphosis of the individual and in the anamorphosis of the species and genera is progressive, and indicative of affinity with a higher type. But among the Crinoideæ proper, and as I have shown among the Cystideæ and the allied or composing families, the contrary is the case.

The anamorphosis of the groups, and possibly the metamorphosis of the individual, are retrograde.

Without the recognition of the influence of the relation of polarity among the Echinodermata, it is impossible to understand the true position of the Cystideæ in the series. To understand their variety and serial parallelism among themselves, we must have recourse to a relation equally mysterious.

Throughout both animal and vegetable kingdoms groups of whatever degree and even species, exactly equivalent in value and manifestly parallel, present certain contrasting features, which when forcibly exhibited, manifest themselves respectively in concentration and elongation, combination and articulation, and the tendency towards the formation of an endosceleton, contrasting with that which rather developes an exoskeleton. This contrast of characters when manifested in the animal kingdom has been styled *the representation of the vertebrate and articulate sphere.* But it is equally manifest in animal and vegetable kingdoms, which indeed these so called spheres represent. There is a striking analogy between the contrasting relations of such parallel groups and those which are in relation of polarity with each other.

When, however, we recognise the true position of the *Cystideæ* as succeeding and continuing the Echinodermal series above the *Crinoidea*, we perceive, as we advance, the successive generic types mastering the opposing polar influence, and manifesting, more and more, their proximity towards the centre or typical portion of the Echinodermal circle. I have shown that the *Cystideæ* progress in two parallel sub-series. In such parallel groups we should find the representation of the spheres manifesting itself. Such is the case. On the one side we have concentration and embodiment of parts rapidly enforced; on the other, the combined polar and articular influences prevent the suppression of the crinoidal type, and separation and articulation of organs, disjunction of arms from the body, &c., all indicate the difficulty with which the adverse influence is overcome. The *Pseudocrinus*, *Agelacrinites*, *Pentremites*, and even *Ophiura*, continually remind us of Crinoids; and this resemblance of the two first-named genera to that group has misled most who have studied them. On the other hand *Sphæronites* and *Palæchinus* present but few traces of their crinoidal predecessors, though linked indubitably with them through *Echino-encrinites* and the allied genera.

When we pass as it were the centre of the Echinodermal circle and ascend in the series, we find the flowing tide of the ascending polar influence as powerful in bearing us upwards through a rapid succession of more and more perfect forms, as the descending current was in impeding the progress of development. The Spatangus and its allies are

advances on the type of the Echinus; the successive forms of Holothuriadæ on both; till, in the Sipunculidæ, few external traces of the type to which they and it belong are left.

The view which I have here taken of the position of the Cystideæ in the Echinodermal series, and of the causes of that position, will appear to those unaccustomed to look upon natural history questions in the abstract, fanciful and perhaps obscure. This is not the place to discuss the ideas it involves, which, whether as yet generally received or not, appear to me to be consistent with each other, and to be borne out by observation and induction. I have no hesitation, therefore, in putting forward this application of them to the illustration of a most interesting and curious group of organized beings—one which, but for geology, would have ever remained unknown, and which, being known, supplies a wanting link in the great chain of nature—confident that, as natural history becomes more and more philosophically studied, such views will gain in interest and scientific value.

EXPLANATION OF THE PLATES.

Plate XI.

Pseudocrinites bifasciatus.

1 and 2. Views of the two sides, as shown in a specimen in the collection of Mr. Capewell. In 1, the ovarian pyramid and the elongated superior rhomb are shown; in 2, the smaller superior and the inferior or basal rhombs.

3. Partial restoration of a specimen in the collection of Mr. J. Gray.
4. One of the lateral plates, showing the peculiar sculpture.
5. Part of a tentacle, with the ossicles of the arm which bear it.
6. Part of arm, with bases of several tentacles.
7. Portion of stem.

Plate XII.

Pseudocrinites magnificus.

1. Specimen in Mr. J. Gray's cabinet, drawn of the natural size.
2. Restored tentacle, and the ossicles of the arm upon which it is articulated.
3. The basal rhomb. The two halves or semi-rhombs are seen occupying opposite portions of two plates.
4. Diagram exhibiting a projection of the plates of a two-armed *Pseudocrinites,* dissected.

Plate XIII.

Pseudocrinites quadrifasciatus.

1. Specimen; natural size; exhibiting the arrangements of stem and body.
2. Outline of oral extremity of the tumid variety.
3. Outline of oral extremity of a compressed variety.
4. Variety with abbreviated arms.
5. Largest of the superior rhombs.
6. Ovarian pyramid.

7, 8, 9, 10. The four sides, showing the arrangement of the plates with respect to the arms.

11. Structure of tentacula and basal ossicula.
12. Arrangement of the impressions of the ossicula of the arms on the angles of the body beneath them.
13. Arrangement of the ossicula of the arms.

Plate XIV.

Pseudocrinites oblongus.

1, 2. Body; natural size; from Mr. Fletcher's collection. 3. As seen from above.

4. Compressed variety, with its stem.

6, 7, 8, 9. Outlines of the four sides, showing the relative positions of the ovarian pyramid and rhombs.

10. Ovarian pyramid.

11. One of the superior rhombs.

12. One of the lateral plates, showing the peculiar sculpture.

13. Structure of a tentacle.

14. Structure of part of an arm.

Plate XV.

Apiocystites pentremitoides.

1. View of body; natural size; from Mr. Gray's specimen. 2. The superior surface. 3. The basal surface.

4. Arrangement of mouth, anus, and arms, as seen from above.

5, 6, 7, 8. The four sides, exhibiting the arrangements of plates, ovarian pyramid, and rhombs.

9. Part of an arm, lodged in its groove.

Plate XVI.

Prunocystites Fletcheri.

1. Specimen in the collection of Mr. Fletcher, drawn of the size of nature.

2. The same greatly enlarged, showing the arrangement of the body, stem, and tentacles.

3. Part of the largest tentacle, greatly magnified.

4. Part of one of the smaller tentacles.

Plate XVII.

Echinoencrinites baccatus.

1, 3, 4. Views of a specimen in the collection of Mr. Buckman.

2. Specimen in Miss Jukes's collection.

5. Oral and anal apertures, with surrounding plates; ovarian pyramid.

6. Oral ossicula, as partially preserved in Miss Jukes's specimen.

7. Circa-ovarian ossicula.

8. Three of the lateral plates, with their peculiar structure, and two semi-rhombs.

9. Imperfect specimen, showing the proportions of body and stem, in a specimen in the collection of Mr. Capewell.

10. Section of the same, showing peculiar appearances connected with the pectinated rhombs.

Plate XVIII.

Echinoencrinites armatus.

1, 2, 3, 4. Views of the body; natural size; from specimens in Mr. Buckman's and Mr. Fletcher's collections.

5. The oral and anal apertures and surrounding ossicula. 6. The anal aperture much enlarged.

7, 8. The ovarian pyramid restored. 9, 10. Remains of it in a specimen belonging to Mr. Capewell.

11. The plates of the ovarian pyramid dissected.

12. Lateral plates, showing their sculpture, and the form of one of the rhombs.

13. Side view of one of the tuberculiferous lateral plates.

14. Dissection of the body, projected on a plane.

Plate XIX.

Echinoencrinus armatus. Varieties.

1, 2, 3, 4. Short variety, with very large tubercles on the infra-ovarian plates; communicated by Mr. Buckman.

5. Dissection and projection of the same.

6. Sculpture of the plates.

7, 8, 9, 10. Variety with the full number (3) of pectinated rhombs, in the cabinet of Mr. Lewis, of Wolverhampton.

Plate XX.

Hemicosmites (in the collections of the Geological Survey).

1 and 1*. Plate of *Hemicosmites squamosus.*

2, 3, 4, 5. Plates of *Hemicosmites pyriformis* (termed *H. rugatus* in this volume, part i., p. 302.)

6. *Hemicosmites oblongus* ?

7. Diagram showing the structure of a *Hemicosmites*, according to the views of Von Buch.

Plate XXI.

Caryocystites (in the collections of the Geological Survey).

1. *Caryocystites pyriformis.—a* and *b.* Specimen showing the ovarian pyramid. *c* and *d.* Basal portion of specimens from Bala. *e.* Sculpture of surface.

9. *Caryocystites Litchi.—a, b.* Entire specimen, showing external surface and cast. *c.* Impression, showing the peculiar superficial ornament. *d.* The same magnified. *e.* Twin pores of surface. *f* and *g.* Impressions of plates, magnified.

3. *Caryocystites munitus.—a* and *b.* Specimens; natural size. *c.* Outline of one, much magnified.

4. *Caryocystites granatum*, from Bala.

5. *Caryocystites Davisii.—a,* side view; *b,* base.

Plate XXII.

Sphæronites.

1. *Sphæronites aurantium.—a.* Specimen, showing the base. *b.* Cast, showing the plates. *c.* External structure of the plates: all from Wales, and in the collections of the Geological Survey.

2. *Sphæronites punctatus.—a.* Specimen, showing test and cast, from Bala. *b.* Part of the surface, magnified. In the collections of the Geological Survey.

3. *Sphæronites balticus.*—From Wales: in the collections of the Geological Survey.

4. *Sphæronites arachnoideus.—a.* Entire specimen, showing cast and sculpture of plates. *b.* Magnified view of the sculpture near the base. From Wales: in the collections of the Geological Survey.

Plate XXIII.

Agelacrinites Buchianus.

1. Upper surface; natural size.

2. Under surface.

3. Side view.

4. Arrangement of arms around the mouth, magnified.

5. One of the segments between the arms, showing the numerous and irregular plates of the body.

6. Impression of under surface, showing the soft space around the peduncles. 7. Portion of the same, magnified.

8. Groove for arm. 9. Part of arm. 10. Section of arm.

11. Supposed stem. 12. Its internal structure. 13. One of the articulations.

14, 14*. Body, supposed to be the base of an *Agelacrinites.*

First Report *on the* Coals *suited to the* Steam Navy, *addressed to the Right Hon. Viscount* Morpeth, *Chief Commissioner of Woods, &c., by Sir* Henry De la Beche *and Dr.* Lyon Playfair.*

Museum of Practical Geology,
January 5, 1848.

My Lord,

We have the honour to transmit a First Report on the experiments which, under the sanction of the Earl of Lincoln, your Lordship's predecessor, we were requested by the Lords Commissioners of the Admiralty to superintend, respecting the value of different varieties of

* The following letter having been addressed to the Lords of the Admiralty, and the official references having been made, the subject was undertaken by the Museum of Practical Geology:—

My Lords, *Bryanstone Square, June* 10, 1845.

When a reward was voted to Mr. Grant, for his patent rights to an artificial fuel, I had a strong desire to oppose the vote, as I was then anxious that the Admiralty should have ordered an inquiry into the several kinds of fuel that might be used for steam-engines, with the view of ascertaining what fuels have the greatest evaporating power in the smallest space and weight.

I am informed that no inquiry of that nature has been instituted by any department of the Government, and therefore beg to recommend the subject as one deserving the immediate and serious attention of your Lordships.

The efficiency of the steamers must depend on the quality of the coals and fuel used for the Naval service, and without an accurate knowledge of the power of the coals to be used, the country may be paying the highest prices for an inferior article; and, depending on the power of the fuel, the public service may suffer disappointment at a moment when the greatest interests of the country may be at stake.

In whatever manner the supply of fuel for marine steamers is received, the importance of the inquiry I venture to recommend must become manifest to your Lordships, and a hope, therefore, the subject may receive attention.

The late Mr. A. P. Upham, of the United States, was strongly impressed with the importance of determining the nature and qualities of the several coals in the United States, with a view to their use in the steam navy of that country; and in 1842–3, directed a course of experiments to be made on the different kinds of coals of the United States, for the purpose of ascertaining their evaporative powers.

I have only this day received from the United States the report of that inquiry, and I have the satisfaction of sending a copy of that report to your Lordships, that you may see the result of that inquiry. They have decided by direct and practical tests the comparative usefulness of American and of English coals, as well as the relative value of the former in their numerous varieties; and I submit to your Lordships that a similar inquiry should be instituted into the comparative usefulness of the several kinds of English, Scotch, and Irish coals, with the view of ascertaining the best for the naval steamers of this country.

I may be allowed to point out to your Lordships that there is a public establishment in Craig's-court perfectly qualified to apply the requisite direct and positive tests to the coals without delay, and to that establishment may be added one chemist of eminence to assist in what is an object of great national importance.

I have, &c.,
(Signed) Joseph Hume.

British coals, for the purposes of our naval service; and, according to your Lordship's instructions, we have forwarded a copy of this Report to the Admiralty, as the expenses of the investigation were incurred by that establishment.

The utility of such investigations having been fully recognized, both as regards questions of the greatest importance connected with our steam navy and as bearing on various branches of our national industry, in which the right use of our fossil fuel is so requisite, it is unnecessary to dwell on the practical application of the inquiry.

We would, however, observe, that experiments necessary to ascertain the true practical value of coal involve a very large series of observations, extended over a considerable period, and directed to special objects of inquiry. The qualities for which particular kinds of fuel are pre-eminent being so varied, it is impossible to deduce general results from a limited series of observations. Even in the one economical application of coals, their evaporative value, or their power of forming steam, one variety of coal which may be admirably adapted from its quick action for raising steam in a short period, may be far exceeded by another variety, inferior in this respect, but capable of converting a much larger quantity of water into steam, and therefore more valuable in the production of force. A coal uniting these two qualities in a high degree might still be useless for naval purposes, on account of its mechanical structure. If the cohesion of its particles be small, the effect of transport, or the attrition of one coal against another by the motion of a vessel, might so far pulverize it as materially to reduce its value. Even supposing the three qualities united, rapidity and duration of action with considerable resistance to breakage, there are many other properties which should receive attention in the selection of a fuel without the combination of which it might be valueless for our steam navy.

There is an important difference existing between varieties of coals in the bulk or space occupied by a certain weight. For the purposes of stowage-room this cannot be ascertained by specific gravity alone, because the mechanical formation of the fragments of coal may enable one of less density to take up a smaller space than that occupied by another of a higher gravity. This is far from an imaginary difference, being sometimes as great as 60 per cent., and not unfrequently 40 per cent. The mere theoretical determination of the density of coals would, therefore, give results useless for practice. The space occupied between two varieties of coals, often equally good as regards their evaporative value, differs occasionally 20 per cent., that is, where 80 tons of one coal could be stowed, 100 tons of another of equal evaporative value might be placed, by selecting it with attention to its mechanical struc-

ture. These facts are mentioned merely to show that a hasty generalization should not be made, and to account for our drawing attention to these various points as a means of preventing the selection of a fuel from any one quality. We do not, in the present state of this inquiry, consider it proper to offer any recommendation of our own as to particular kinds of fuel, leaving the experimental facts to decide for themselves.

After preliminary experiments had proved that no practical result could be attained by mere laboratory research, it was determined to test each variety of coal on a scale of sufficient magnitude to check the theoretical views by the practical results. As it was impossible for either of us to devote our whole time to this inquiry, our services being required by other official duties, we appointed assistants to superintend its special parts, under our general direction. On the selection of assistants we have reason to congratulate ourselves, their duties having been conducted with great care and skill. To Mr. Wilson, since appointed Principal of the Royal Agricultural College of Cirencester, whose practical knowledge well fitted him for the task, the superintendence of the economical part of the experiments was first confided. To him and Mr. Phillips is due the erection of the boilers, and the experiments, to illustrate the practical evaporative power of the coals. After Mr. Wilson had for some time proceeded with the investigation, he was joined by Mr. Kingsbury, who volunteered his services to this department. The latter gentleman was formerly a distinguished student at the College for Civil Engineers, Putney, and from his engineering skill has rendered an especial service to this inquiry.

On the translation of Mr. Wilson to Cirencester, the practical superintendence of the investigation was intrusted to Mr. J. Arthur Phillips, a pupil of the École des Mines of Paris. The information obtained had pointed out improvements and corrections in the processes used, to which Mr. Phillips applied himself with much skill and success.

The corrections and the results of his experiments will be found in his appended Report. The excellent scientific education of Mr. Phillips, and his practical resources, rendered his services of great value.

The analyses of coals were intrusted to Mr. Wrightson (a pupil of Liebig), who had fitted himself by special study for an undertaking requiring so much delicacy of manipulation. Mr. Galloway, an assistant at the Museum of Practical Geology, gave his occasional services in analyzing gases and ashes from the furnaces, but he was not wholly retained for this purpose.

Mr. How, a very careful experimentalist, and assistant at the laboratory of the College for Civil Engineers, was appointed analyst after the retirement of Messrs. Wrightson and Galloway.

It is proper to mention, in terms of approbation, the services of the intelligent working engineer, William Hutchinson, whose assiduity soon enabled him to be of more important service than was to have been expected from his position.

The results obtained by the assistants, with accounts of the modes pursued, are appended, in order that the methods may be examined, and that special attention may be devoted to any particular department of the inquiry.

In the first section of the Appendix, a full description is given of the processes adopted in conducting the practical part of the experiments, as also plans and sections of the boiler, furnace, and apparatus employed.

The second section contains details of the observations and experiments made to ascertain the evaporative power of the different varieties of coals; and describes the formulæ used for calculating the experiments, and for correcting and reducing them to one standard.

The third section contains the chemical experiments, including the ultimate and proximate analyses of the coals, and the determination of their calorific values.

It is unnecessary to repeat here the mode in which the experiments were instituted, as these are detailed in the first section of the Appendix, so that it will suffice to draw attention to the points observed in reducing and calculating the results. It will be obvious that there are several circumstances which must receive attention before the true evaporative value of a fuel can be obtained. Thus, the water in the tanks has a varying temperature during the day, dependent on atmospheric changes, and is always different from that in the boiler. The temperature of water in the boiler also varies with the external temperature, and the circumstances under which the experiments are made. The shape of a Cornish boiler favours an inequality in the temperature of the water in its various parts, the colder and denser water sinking to the bottom, and having a tendency to remain there, so that the temperature of water at the surface is far from being the mean temperature of water in the boiler, the difference between the surface and bottom water being, on an average, 70°. Other circumstances naturally affect the the evaporative powers of the coal—as, for example, the fact that all the water exposed to the action of the fire in the boiler is not converted into steam, and that wood is used to light the fire. Another circumstance of considerable importance, is the expansion or contraction of the boiler from an increase or diminution of the temperature. In the early stage of the experiments, those conducted by Messrs. Wilson and Kingsbury, it was thought unnecessary to make a correction for this variation in conditions; but on ascertaining experimentally that the difference was as much as

69·625 lbs. of water in the contents of the boiler, between the temperature 150° and 212°, it became desirable to make an allowance for it, even when the difference between the initial and final temperature was not greater than 10°. Other circumstances of less importance, but influencing the results, have been neglected, because the application of such corrections would have only complicated the results, and would have had little practical value when the errors of observation in such approximative experiments remain so large. Among these may be mentioned the quantity of gases evolved during combustion, the elevation in temperature of the air entering the fire-place, the barometrical and hygrometric conditions of the atmosphere, the radiation from the boiler (very small in amount, owing to its brick covering), the hygrometric state of the fuel, or the heat necessary for obtaining mechanical draught in the chimney. In most of these cases the necessary observations have been made, to enable the corrections to be applied, should it afterwards appear desirable.

In making the calculation for the evaporative value of a fuel, the quantity consumed was divided into two portions, the first being that necessary to raise the whole mass of water, exposed to the fire, from the *mean temperature* to 212°, the second portion being that required to evaporate the water taken from the tanks from a temperature of 212°. To enable this to be done, the mean temperature of the whole mass of the water is ascertained, that is, the temperature of the water in the boiler at its initial temperature after being mixed with the tank water at its average temperature. The average of the latter was the mean of several observations taken during the day, and is designated by t'.

Let w be the weight of water drawn from the tanks at temperature t'
W ,, in boiler ,, t''
this being obtained from the surface temperature corrected by experiment. Let t be temperature after mixture.

$$\text{Then } t = \frac{W\,t'' + w\,t'}{W + w}.$$

The correction for the wood was made from data procured experimentally by Messrs. Wilson and Kingsbury, but it can only be employed for the particular wood used, as in subsequent experiments the evaporative value was found very different from another quality obtained. The coefficient of the evaporative power of the wood may be deduced from experiment, in which a certain weight of water was raised from a known temperature to the boiling point, and then a certain portion of it evaporated. The following formulæ have been used by Mr. Kingsbury for the calculation—

N is the total weight of wood used in raising (W + w) (the weight of

water in the boiler, and of that let down from the tanks during the experiment) from the mean temperature t to 212°; then it is necessary to find the weight N′ necessary to evaporate w from 212°.

Then $\frac{w}{N'} = e$, the evaporating power.

Let m be the weight of wood required to raise $W + w$ from t to 212°, the number 1000 being assumed as the latent heat of steam.

N to evaporate $W + w$ from 212°
N′ ,, w ,,

$$\text{Then } m + N' = N$$

$$\text{Now } \frac{l}{212 - t} = \frac{n}{m}$$

$$\text{But } \frac{n}{N'} = \frac{W + w}{w}$$

$$\therefore N' = n \frac{w}{W + w}$$

$$l\,(N - N') = (212 - t)\,n$$

$$= (212 - t)\,N' \left(\frac{W + w}{w}\right)$$

$$N\,l = N' \left\{\frac{W + w}{w}(212 - t) + l\right.$$

$$= \frac{N'}{w}\Big\}(212 - t)(W + w) + l\,w$$

$$\therefore \frac{w}{N'} = \frac{(212 - t)(W + w) + l\,w}{N\,l}$$

$$= e$$

Or, introducing the value of t as given by the first formula,

$$\frac{(l + 212 - t)\,w + (212 - t'')\,W}{N\,l} = e.$$

If q be the quantity of wood used in lighting the fire, $e\,q$ will be the weight of water evaporated from 212° by the wood, and must be deducted from the weight of water evaporated in calculating the work done by the coal.

The coefficient of the evaporating power of the coals, or the number of lbs. of water which one lb. of coal will evaporate from 212°, may be calculated as follows:—

Let P be the total quantity of coal consumed, then the work done by P will be to raise $W + w$ of water from t to 212°, and to evaporate $w - e\,q$ from 212°.

Let m be the weight of coal required to raise $W + w$ to 212° from t
p „ „ evaporate $w - e\,q$ from 212°
n „ „ „ $W + w$ from 212°

Then $\frac{w - e\,q}{p} = E$, the evaporating power.

Now $P = m + p$

$$\frac{212 - t}{l} = \frac{m}{n}$$

But $\frac{p}{n} = \frac{w - e\,q}{W + w}$

$$\therefore\ l\left(\frac{w - e\,q}{W + w}\right) = p\,\frac{212 - t}{P - p}$$

$$\frac{(W + w)(212 - t) + (w - e\,q)\,l}{P\,l} = \frac{w - e\,q}{p}$$
$$= E$$

Introducing the values from which the mean temperature t was obtained (first formula), we have eventually

$$\frac{(l + 212 - t')\,w + (212 - t'')\,W - l\,e\,q}{P\,l} = E$$

in which W is the weight of water in the boiler;
w „ drawn from the the tanks during the experiment;
t' the mean temperature of water in tanks;
t'' the corrected initial temperature of water in the boiler.*

* A small correction must be also made for the combustible matter in the *residua* of combustion, such as the soot and carbonaceous matter in the ashes: to do this with great accuracy, a series of observations and analyses would have been required, the labour and expense of which would not have been warranted by the amount of correction necessary. It was, therefore, considered sufficient to proceed as follows,—although the result is nothing more than a very rough approximation to the truth. For such an approximation it will be admitted that the evaporative value of the coal depends on the ratio of the combustible to the incombustible matter, and that this ratio confers a similar evaporative value on the quantity of ashes, cinders, and soot produced by the combustion; in other words, that if the combustible matter of the latter had been usefully applied in the production of steam, a similar effect would have been produced as if a corresponding quantity of coal had been burned. If then Q be the weight of coal containing the same quantity of combustible matter as the *residua* after its combustion in the furnace—

$$\frac{(l + 212 - t')\,w + (212 - t'')\,W - l\,e\,q}{(P - Q)\,l} = E',$$ the corrected coefficient of evaporating power.

Let then w_1 = weight of ashes after the experiment
w_2 = „ cinders „ „
w_3 = „ soot „ „

The weight of the cinders is taken after the clinkers are separated.

Let

In the preceding formulæ, the latent heat of steam has been taken at 1000°, the number generally used in this country; but after all the calculations had been made on this subject from the experiments by Messrs. Wilson and Kingsbury, and the results sent in to the Admiralty, Regnault's excellent memoir on the latent heat of steam was published. It became necessary, therefore, to use these new results in the future experiments. These, so far as they apply to the present inquiry, are reduced in the following table:—

TABLE No. I.—*Showing the Specific and Latent Heat of Water and Steam.*

Air Thermometer Centigrade.	Mercurial Centigrade.	Number of Unities of Heat abandoned by one kilo. of water in descending from T to 0.	Air Thermometer Fahrenheit.	Mercurial Fahrenheit.	Number of Unities of Heat contained in one pound of water at T°.	Mean Specific Heat of Water between 0° and T cent. or between 32° and T Fahr.	Specific Heat of Water from T to T + d T.	Latent Heat of Steam saturated to the temperature T. Centigrade.	Fahrenheit.
°	°		°	°					
0	..	0·000	32	..	32·000	..	1·0000	606·5	1091·7
10	..	10·002	50	..	50·003	1·0002	1·0005	599 5	1079·1
20	..	20·010	68	..	68·018	1·0005	1·0012	592·6	1066·7
30	..	30·026	86	..	86·046	1·0009	1·0020	585·7	1054·2
40	..	40·051	104	..	104·091	1·0013	1·0030	578·7	1041·6
50	50·2	50·087	122	122·36	122·156	1·0017	1·0042	571·6	1028·9
60	..	60·137	140	..	140·246	1·0023	1·0056	564·7	1016·4
70	..	70·210	158	..	158·381	1·0030	1·0072	557·6	1003·7
80	..	80·282	176	..	176·507	1·0035	1·0089	550·6	991·1
90	..	90·381	194	..	194·685	1·0042	1·0109	543·5	978·3
100	100·0	100·500	212	212·0	212·900	1·0050	1·0130	536·5	965·7
110	..	110·641	230	..	231·153	1·0058	1·0153	529·4	952·9
120	..	120·806	248	..	249·450	1·0067	1·0177	522·3	940·1
130	..	130·997	266	..	267·794	1·0076	1·0204	515·1	927·2
140	..	141·215	284	..	286·187	1·0087	1·0232	508·0	914·4
150	150·0	151·462	302	302·0	304·632	1·0097	1·0262	500·7	901·2
160	..	161·741	320	..	323·133	1·0109	1·0294	493·6	888·5
170	..	172·052	338	..	341·693	1·0121	1·0328	486·2	875·1
180	..	182·398	356	..	360·316	1·0133	1·0364	479·0	862·2
190	..	192·779	374	..	379·002	1·0146	1·0401	471·6	848·9
200	200·0	203·200	392	392·0	397·760	1·0160	1·0440	464·3	835·7
210	..	213·660	410	..	416·588	1·0174	1·0481	456·8	822·2
220	..	224·162	428	..	435·480	1·0189	1·0524	449·4	808·9
230	..	234·708	446	..	454·474	1·0204	1·0568	441·9	795·4

It also became desirable to introduce new corrections, which the progress of the inquiry showed to be needful. Thus, Mr. Phillips's careful experiments determined the alteration in the capacity of the boiler at different temperatures, and correction was in future made for this difference. The alteration in the capacity of the measuring tanks was also estimated, whenever the temperature differed 2° from that at

---

Let $\left.\begin{matrix} r_1 \\ r_2 \\ r_3 \end{matrix}\right\}$ be the per centage of combustible matter in the ashes, cinders, and soot respectively;

Q the weight of coal containing the same weight of combustible matter;

r the per centage of combustible matter as found in the coal by analysis;

Then
$$r\,Q = r_1\,W_1 + r_2\,W_2 + r_3\,w^3$$
$$\therefore\quad Q = \frac{r_1\,W_1 + r_2\,W_2 + r_3\,w^3}{r}.$$

which they were gauged. Another cause of error, for which allowance should be made, is any difference which may exist between the initial and final temperature at the beginning and close of the experiment. This difference being known by observation, the correction may be applied from the Table of Expansion of the Water in the Boiler, given in the Appendix. Introducing these new corrections into the experiments for ascertaining the coefficient of the heating power of the wood, the following are the formulæ used by Mr. Phillips :—

$$\frac{(W + w - w')\ (l + t)\ + wt' + (w' - w)\ t''}{P\ l} = E.$$

In which W is the water let down from the tanks during the experiment.

$w =$ The weight of water (as found by the Table of Expansion) found in the boilers at commencement of experiment.

$w' =$ The weight of water in boiler at close of experiment.

$l =$ Coefficient of the latent heat of steam.

$t =$ Quantity of heat necessary to raise the water in tanks from its mean temperature to that at which it is evaporated.

$t' =$ Quantity of heat necessary to raise the water in the boiler from the initial to the final temperature.

$t'' =$ Quantity of heat necessary to raise water at the temperature of tanks to the final temperature of water in the boiler.

$P =$ Weight of combustibles consumed during experiment.

$E =$ The coefficient of the heating powers of wood.

But when the initial is lower than the final temperature, the formula becomes—

$$\frac{(W + w - w')\ l + Wt + wt' + (w' - w)\ t'''}{P\ l} = E.$$

All the terms retaining their original value except the last, in which t'' is replaced by t''' (or the heat necessary to raise the final temperature to that at which the water was evaporated), and must be regarded as having a negative value, while t' becomes positive. If now q is the weight of wood used in lighting the fire, the formulæ for estimating the evaporative power of the coal will be

$$\frac{(W - E\,q + w - w')\ l + (W + w - w')\ t + wt' + (w' - w)\ t''}{P\ l} = E'.$$

And

$$\frac{(W - E\,q + w - w')\ t + Wt + wt' + (w' - w)\ t'''}{P\ l} = E'.$$

As the experiments are strictly comparative, and under like conditions, the want of the other corrections, to which we have alluded above, will not be felt in examining the results ; while their execution

would have introduced a refinement into the experiments which never could be obtained in practice, and which, in fact, would be useless and unwarrantable, while, as previously remarked, the errors of observation in all such approximate experiments remain so large.

The only omitted correction which in appearance might be supposed necessary for practical purposes, is that for the hygroscopic condition of the fuel. Had wood been employed, this must have been done; but the hygroscopic nature of coal is very much less than that of wood. The latter contains $\frac{1}{5}$ of its own weight of hygroscopic water; and the heat necessary for the evaporation of this quantity might be shown by a simple calculation to be nearly equal to 22 per cent. of the total heat obtained by the combustion of the wood. The hygroscopic water in coal is however very small, as will be seen by the following determinations of some of the Welsh specimens experimented upon :—

	Hygroscopic water.
Graigola Coal . .	1·06 per cent.
Anthracite . . .	2·44 „
Old Castle . . .	0·74 „
Ward's Fiery Vein .	1·27 „
Mynydd Newydd . .	0·67 „
Pentrepoth . . .	0·78 „
Pentrefelin . . .	0·70 „

Had we introduced corrections for these small quantities, practice would have been misled ; because the coals will rarely reach a vessel in the dry state that they did in the present case, when they were packed in hogsheads and kept under cover.

It was found unnecessary to correct for any inflammable gases flying up the chimney, because repeated analyses of the chimney gases proved them not to contain any combustible constituent; the only products ever found being carbonic acid, sulphurous acid, oxygen, and nitrogen. The quantity of free oxygen in the chimney varied from $\frac{1}{4}$ to $\frac{1}{2}$ of the oxygen, which combined with the fuel; in other words, nearly twice the quantity of air passes through the fire than that which is strictly necessary by theory.

With regard to the selection of the coals for trial, we have to refer to Mr. Wilson's letter inserted in the Appendix. This letter gives the information obtained in a tour made by Professor Wilson for the purpose of ascertaining the best coals fitted for trial in the South Wales coal district, and the ports from which they can conveniently be shipped. This district was selected because the varying character of the coals, from the bituminous to the anthracitic, offered those which were most likely to combine the qualities desired for naval purposes. It was

intended, as being most convenient for the inquiry, to have adhered strictly to districts. In the experiments, this has hitherto been done, except in special cases, at the request of the Admiralty.

The following Table contains an abstract of the results, so far as regards the evaporative value of the fuel; the special characters of each of the coals being described in the experiments detailed in the Appendix.

TABLE II.—*Showing the Economic Values of the Coals.*

Names of Coals employed in the Experiments.	Economic evaporating power, or number of pounds of Water evaporated from 212° by 1 lb. of Coal.	Weight of 1 cubic foot of the Coal as used for fuel.—Lbs.	Weight of 1 cubic foot as calculated from the density.—Lbs.	Ratio of B. to C., or of the economical to the theoretical weight.	Difference per cent. between theoretical and economical weights.	Space occupied by 1 ton in cubic feet (economic weight).	Results of experiments on cohesive power of Coals per centage of large Coals.	Evaporating power of the Coal after deducting for the combustible matter in the residue.	Weight of Water evaporated from 212° by 1 cubic foot of Coal.	Rate of evaporation, or number of lbs. of Water evaporated per hour.—Mean.
	A.	B.	C.	D.	E.	F.	G.	H.	I.	
Welsh Coals:—										
Graigola.	9·35	60·166	81·107	·742	34·8	37·23	49·3	9·66	581·20	441·48
Anthracite, Jones and Co.	9·46	58·25	85·786	·679	47·26	38·45	68·5	9·7	565·02	409·37
Old Castle Fiery Vein.	8·94	50·916	80·42	·633	57·946	43·99	57·7	..	455·18	464·30
Ward's Fiery Vein .	9·40	57·433	83·85	·685	46·	39·	46·5	10·6	608·78	529·90
Binea	9·94	57·08	81·357	·702	42·53	39·24	51·2	10·3	587·92	486·95
Llangennech . . .	8·86	56·93	81·85	·695	43·76	39·34	53·5	9·2	523·75	373·22
Pentrepoth	8·72	57·72	81·73	·705	40·17	38·80	46·5	8·98	518·32	381·50
Pentrefelin	6·36	66·166	84·726	·781	28·051	33·85	52·7	7·4	489·62	247·24
Duffryn.	10·14	53·22	82·72	·643	55·43	42·09	56·2	11·80	540·12	409·32
Mynydd Newydd .	9·52	56·33	81·73	·689	45·09	39·76	53·7	10·59	536·26	470·69
Three-quarter Rock Vein	8·84	56·388	83·60	·674	48·26	39·72	52·7	..	498·46	486·86
Cwm Frood Rock Vein	8·70	55·277	78·299	·706	41·648	40·52	72·5	9·35	480·90	379·80
Cwm Nanty-gros. .	8·42	56·0	79·859	·701	42·60	40·00	55·7	8·82	471·52	404·16
Resolven	9·53	58·66	82·354	·712	40·39	38·19	35·0	10·44	559·02	390·25
Pontypool.	7·47	55·7	82·35	·676	47·845	40·216	57·5	8·04	416·07	250·40
Bedwas	9·79	50·5	82·6	·611	63·565	44·32	54·0	9·99	494·39	476·96
Ebbw Vale	10·21	53·3	78·81	·676	45·98	42·26	45·0	10·64	544·19	460·22
Porthmawr	7·53	53·3	86·722	·614	62·7	42·02	62·0	7·75	401·34	347·44
Coleshill	8·0	53·0	80·483	·658	51·85	42·26	62·0	8·34	424·0	406·41
Scotch Coals:—										
Dalkeith Jewel Seam	7·08	49·8	79·672	·625	59·984	44·98	85·7	7·10	352·58	355·18
,, Coronation Seam . . .	7·71	51·66	78·611	·657	52·17	43·36	88·2	7·86	398·29	370·08
Wallsend Elgin . .	8·46	54·6	78·611	·694	43·78	41·02	64·0	8·67	460·82	435·77
Fordel Splint . . .	7·56	55·0	78·611	·699	42·92	40·72	63·0	7·69	415·80	464·98
Grangemouth . . .	7·40	54·25	80·48	·674	48·35	40·13	69·7	7·91	401·45	380·40
English Coals:—										
Broomhill.	7·3	52·5	77·988	·673	48·55	42·67	65·7	7·66	383·25	397·78
Lydney (Forest of Dean	8·52	54·444	80·046	·68	47·02	41·14	55·0	8·98	463·86	487·19
Slievardagh Irish Anthracite. . .	9·85	62·8	99·57	·630	58·55	35·66	74·0	10·49	618·58	473·18
Patent Coals:—										
Wylam's Patent Fuel	8·92	65·08	68·629	·948	5·45	34·41	..	9·74	580·51	418·89
Bell's ,,	8·53	65·3	71·124	·918	8·91	34·30	..	8·65	557·0	549·11
Warlich's ,,	10·36	69·05	72·248	·955	4·49	32·44	..	10·60	715·35	457·84

This Table relates only to the economical value of the coals examined, and to the steam generated by a unit of the respective coals, without

however implying a unit of time. The details with reference to time, which forms a most important element in the value of the respective fuels, will be found in Section II.

The economical results obtained by evaporation in the best-applied practice are ascertained to be only a small part of the theoretical result following from the actual quantity of heat capable of being generated. Still, as a comparative statement, it is necessary to contrast the economical heat given out by a coal with the theoretical quantity. The cause of the difference between the applied and theoretical quantities is, at least in a great degree, obvious, and does not by the apparent difference prove the fallacy of calculation. Before the comparison can be made, it is necessary to have a knowledge of the composition of the respective coals. Of this we subjoin a Table reduced from Section IV.

TABLE III.—*Showing the Mean Composition of average samples of the Coals.*

Locality or Name of Coal.	Specific Gravity of Coals.	Carbon.	Hydrogen.	Nitrogen.	Sulphur	Oxygen.	Ash.	Per centage of Coke left by each Coal.
Welsh Coals :—								
Graigola	1·30	84·87	3·84	0·41	0·45	7 19	3·24	85·5
Anthracite	1·375	91·44	3·46	0·21	0·79	2·58	1·52	92·9
Oldcastle Fiery Vein	1·289	87·68	4·89	1·31	0·09	3·39	2·64	79·8
Ward's Fiery Vein	1·344	87·87	3·93	2·02	0·83	Included in ash.	7·04	..
Binea Coal	1·304	88·66	4·63	1·43	0·33	1·03	3·96	88·10
Llangennech	1·312	85·46	4·20	1·07	0·29	2·44	6·54	83·69
Pentrepoth	1·31	88·72	4·50	0·18	..	3·24	3·36	82·5
Pentrefelin	1·358	85·52	3·72	Trace.	0·12	4·55	6·09	85·0
Duffryn	1·326	88·26	4·66	1·45	1·77	0·60	3·26	84·3
Mynydd Newydd	1·31	84·71	5·76	1·56	1·21	3·52	3·24	74·8
Three-quarter Rock Vein	1·34	75·15	4·93	1·07	2·85	5·04	10·96	62·5
Cwm Frood Rock Vein	1·255	82·25	5·84	1·11	1·22	3·58	6·00	68·8
Cwm Nanty-gros	1·28	78·36	5·59	1·86	3·01	5·58	5·60	65·6
Resolven	1·32	79·33	4·75	1·38	5·07	Included in ash.	9·41	83·9
Ponty Pool	1·32	80·70	5·66	1·35	2·39	4·38	5·52	64·8
Bedwas	1·32	80·61	6·01	1·44	3·50	1·50	6·94	71·7
Ebbw Vale	1·275	89·78	5·15	2·16	1·02	0·39	1·50	77·5
Porthmawr Rock Vein	1·39	74·70	4·79	1·28	0·91	3·60	14·72	63·1
Coleshill	1·29	73·84	5·14	1·47	2·34	8·29	8·92	56·0
Scotch Coals :—								
Dalkeith Jewel Seam	1·277	74·55	5·14	0·10	0·33	15·51	4·37	49·8
Dalkeith Coronation Seam	1·316	76·94	5·20	Trace.	0·38	14·37	3·10	53·5
Wallsend Elgin	1·20	76·09	5·22	1·41	1·53	5·05	10·70	58·45
Fordel Splint	1·25	79·58	5·50	1·13	1·46	8·33	4·00	52·03
Grangemouth	1·29	79·85	5·28	1·35	1·42	8·58	3·52	56·6
English Coals :—								
Broomhill	1·25	81·70	6·17	1·84	2·85	4·37	3·07	59·2
Park End, Lydney	1·283	73·52	5·69	2·04	2·27	6·48	10·00	57·8
Slievardagh (Irish)	1·59	80·03	2·30	0·23	6·76	Included in ash.	10·80	90·1
Foreign Coals :—								
Formosa Island	1·24	78·26	5·70	0·64	0·49	10·95	3·96	..
Borneo (Labuan kind)	1·28	64·52	4·74	0·80	1·45	20·75	7·74	..
,, 3 feet seam	1·37	54·31	5·03	0·98	1·14	24·22	14·32	..
,, 11 feet seam	1·21	70·33	5·41	0·67	1·17	19·19	3·23	..
Patent Fuel :—								
Wylam's Patent Fuel	1·10	79·91	5·69	1·68	1·25	6·63	4·84	65·8
Bell's ,, ,,	1·14	87·88	5·22	0·81	0·71	0·42	4·96	71·7
Warlich's ,, ,,	1·15	90·02	5·56	Trace.	1·62	Included in ash.	2·91	85·1

Chemists differ as to the mode of calculating the theoretical heating values of coals, but, as an approximative rule, without insisting on its absolute accuracy, their calorific values are found to stand in relation to the quantity of oxygen required for their complete combustion. This may be estimated experimentally by heating the coal with an excess of litharge in the manner, and with the precautions described by Mr. Phillips, or it may be determined by calculation from the known equivalents of the combustible ingredients of the coal. From the quantity of lead reduced by the coal, the oxygen employed in its combustion may be estimated, and the calorific values stand in direct relation to this quantity. The amount of oxygen necessary to consume the combustible constituents may more accurately be determined by elementary analysis; and thus calculated, the results are generally found to be about $\frac{1}{9}$ greater than those indicated by experiment with the litharge. The calculation from the elementary analysis depends upon the circumstance, that 6 parts, or one equivalent, of carbon, requires 16 parts, or two equivalents, of oxygen for combustion, while 1 part of hydrogen requires 8 parts of oxygen; it is only necessary, therefore, to subtract from the hydrogen a quantity corresponding to the oxygen contained in the coal to enable the calculation to be made on these principles.

As the calorific values are only relative, it is useful to refer them to the heating power of pure carbon, 1 part of which requires 2·666 parts of oxygen for combustion, and is capable, according to Despretz, of heating 78·15 parts of water from its freezing to its boiling point. The calculation may be simplified by multiplying each part of lead obtained by 2·265, which gives at once the weight of water capable of being heated between these temperatures by a unit of the coal used in reducing the litharge. On these principles the following Table is constructed.—(*See* Table IV., p. 552.)

With regard to the practical application of fuel, such a Table could not supersede experiment, as the economical values of the coal depend also on adventitious circumstances connected with their physical as well as their chemical condition. This Table, while on the whole it agrees with and confirms the practical results of experiments, still differs in a marked degree in one or two instances: this difference arising as much from the chemical as from the physical differences of the coals. Thus, if by destructive distillation, which occurs in furnaces before combustion, a large quantity of the constituents of the coal are rendered gaseous, so much heat is expended in this act that the heat developed by their after combustion is frequently not greater than that abstracted during their formation, in which case a thermo-neutrality occurs. To ascertain the proportion of fixed and volatile products in the various coals, the

TABLE IV.—*Showing the Calorific Values of the Coals.*

Name of Coal.	Quantity of Lead reduced by one part of Coal.	Oxygen removed from Litharge by one part of Coal.	Quantity of Oxygen theoretically required by Carbon and Hydrogen.	Quantity of Oxygen required by Carbon alone.	Relative calorific Values, Carbon taken as 100, calculated from A. and B.	Number of lbs. of Water which 1 lb. of Coal can raise from 32° Fah. to 212° Fah., calculated from A.
	A.	B.	C.	D.	E.	F.
Welsh Coals:—						
Graigola	32·08	2·49	2·49	2·26	93·4	72·66
Anthracite (Jones and Aubrey)	33·48	2·60	2·69	2·43	97·5	75·73
Oldcastle Fiery Vein	31·42	2·44	2·71	2·34	91·5	71·16
Ward's Fiery Vein	31·46	2·44	2·65	2·34	91·5	71·25
Binea Coal	31·64	2·46	2·72	2·36	92·2	71·66
Llangennock	32·66	2·53	2·59	2·28	94·9	73·97
Pentrepoth	31·16	2·39	2·69	2·36	89·6	70·57
Pentrefelin	30·52	2·37	2·53	2·28	89·2	69·13
Powel's Duffryn	30·00	2·33	2·71	2·35	87·7	67·95
Mynydd Newydd	30·34	2·35	2·67	2·25	88·5	68·72
Three-quarter Rock Vein	26·62	2·06	2·34	2·00	77·2	60·29
Cwm Frood Rock Vein	28·30	2·19	2·62	2·19	82·5	64·10
Cwm Nanty-gros	29·64	2·28	2·47	2·08	85·5	67·13
Resolven	32·16	2·50	2·49	2·11	93·7	72·84
Pontypool	27·46	2·13	2·55	2·15	80·2	62·19
Bedwas	28·20	2·19	2·60	2·15	82·1	63·87
Ebbw Vale	32·00	2·48	2·80	2·39	93·0	72·48
Porthmawr Rock Vein	24·78	1·92	2·33	1·99	72·0	56·12
Coleshill	26·14	2·03	2·28	1·96	76·1	59·21
Scotch Coal:—						
Dalkeith Jewel Seam	26·42	2·05	2·24	1·98	76·8	59·84
,, Coronation Seam	24·56	1·96	2·32	2·05	73·5	55·63
Elgin Wallsend	29·06	2·25	2·38	2·02	84·7	65·82
Fordel Splint	29·00	2·25	2·47	2·12	84·7	65·68
Grangemouth	28·48	2·20	2·46	2·13	82·8	64·51
Broomhill (English)	25·32	1·96	2·63	2·18	73·5	57·35
Slievardagh (Irish)	30·10	2·33	2·31	2·13	87·7	70·44
Patent Fuels:—						
Wylam's Patent Fuel	28·82	2·23	2·52	2·13	84·0	65·27
Bell's ,, ,,	28·52	2·21	2·75	2·34	83·2	64·59
Warlich's ,, ,,	31·50	2·44	2·84	2·40	91·5	71·35

very difficult and elaborate process, described in Section III., was adopted; but the tediousness and chances of failure in this kind of analysis have only induced us to include a limited number of coals (those given in Table V.), especially as for steam purposes it was sufficient to determine the per centage of coke, as stated in Table II.

TABLE V.—*Showing the Amount of various Substances produced by the destructive Distillation of certain Coals.*

Name.	Coke.	Tar.	Water.	Ammonia.	Carbonic Acid.	Sulph. Hydrogen.	Olefiant Gas and Hydro-Carbon.	Other Gases inflammable.
Welsh Coals:—								
Graigola	85·5	1·2	3·1	0·17	2·79	Traces.	0·23	7·01
Anthracite, from Jones, Aubrey, and Co.	92·9	None.	2·87	0·20	0·06	0·04	?	3·93
Oldcastle Fiery Vein	79·8	5·86	3·39	0·35	0·44	0·12	0·27	9·77
Ward's Fiery Vein	..	1·80	3·01	0·24	1·80	0·21	0·21	..
Binea	88·10	2·08	3·58	0·08	1·68	0·09	0·31	4·08
Llangenneck	83·69	1·22	4·07	0·08	3·21	0·02	0·43	7·28

It has been for some time asserted, that the evaporative value of a bituminous coal is expressed by the evaporative value of its coke, the heat of combustion of its volatile products proving in practice little more than that necessary to volatilise them. If this supposition were even near the truth, the most useful practical results might follow from it. By a larger and better applied system of gas manufacture, the volatile products of distillation might be made useful not only for the purposes of illumination, but also for domestic heat, and the residual coke might be used with an equal economy in our manufactures;* thus preventing the emission of that smoke, which, at present, is so destructive to the comfort of our large cities. It is easy from analysis to examine whether the duty performed by the coal is to be attributed to its fixed ingredients or coke, by estimating the work which the latter is capable of performing. This may be done by subtracting the amount of ashes in the coal from its amount of coke (Table III.) and estimating the remainder as carbon. This carbon multiplied by its heating power, 13268, and divided by 965·7 or the latent heat of steam, indicates the number of pounds of water which the coke by itself could evaporate, without the aid of the combustible volatile ingredients of the coal. These results are placed in column B. of Table VI., in juxtaposition with the actual work done by the coal; and it will be seen, that notwithstanding several striking exceptions, which might have been expected, they on the whole show that the work capable of being performed by the coke alone, is actually greater than that obtained by experiments with the original coal.

The whole system of manufacturing coke is at present very imperfect. Besides losing the volatile combustible substances, which under new adjustments might be made of much value, an immense quantity of ammonia is lost by being thrown into the atmosphere. Ammonia and its salts are daily becoming more valuable to agriculture, and it is their comparative high price alone, which prevents their universal use to all kinds of cereal cultivation. By a construction of the most simple kind, the coke ovens now in use might be made to economise much of the nitrogen which invariably escapes in the form of ammonia. As an inducement to this economy, we have appended to Table VI. two columns (H. and I.), showing the quantity of ammonia ($N\,H_3$), and its corresponding quantity of commercial sulphate ($N\,H_4\,O,\ S\,O_3$), which each 100 lbs. of the respective coals may be made to produce. When it is remembered, that the price of sulphate of ammonia is about £13 per ton, or that 100 tons in coking is capable of producing,

* In this case it would be necessary not to carry on the process of distillation so far as at present, as the residual coke would be more combustible and the gases purer.

on an average, about 6 tons of this salt, its neglect is highly reprehensible.

By the preceding data, the actual value of the coals will be contrasted with that which is theoretically possible, supposing their combustion proceeded under circumstances which prevented any loss of heat. The actual duty obtained by a pound of coal from the boiler employed may be easily expressed by the number of pounds raised to the height of one foot. This result may readily be obtained by the simple formula—

$$W n \times 965 \cdot 7 \times 782 = x,$$

W representing water, of which n pounds are evaporated by a pound of coal. This formula is deduced from the fact that n pounds of water multiplied by 965·7,* or the coefficient for the latent heat of steam at 212°, indicates the number of pounds of water which would be raised 1° Fah.; and the number 782 arises from experiment on the mechanical force denoted by the elevation of a pound of water 1° Fah.; that force being equal to 782 lbs., raised to the height of one foot, according to the careful experiments of Mr. Joule, on the friction of oil, water, and mercury.

The theoretical value of the coals, with reference to the number of pounds of water which one pound of fuel will convert into steam, is obtained by the formula—

$$\left(\frac{C \times 13268}{965 \cdot 7}\right) + \left(\frac{H - h \times 62470}{965 \cdot 7}\right) = x,$$

in which C is the quantity of carbon, H the quantity of hydrogen in a unit of fuel, and h the quantity of oxygen corresponding to the oxygen contained in the coal. These multiplied by their heating powers, according to the results of Dulong, and divided by the latent heat of steam, indicate the number of pounds of water that can be converted into the latter by a pound of coal. The numbers thus obtained can be changed into the expression of mechanical force, by the previous formulæ.

The results of these calculations are thrown into Table VI.—(*See* page 555.)

The best Cornish engines are stated to raise 1,000,000 lbs. to the height of one foot, by every pound of coal consumed; so that only about $\frac{1}{8}$ of the *actual* force generated becomes available, or only $\frac{1}{11}$ or $\frac{1}{12}$ of the force theoretically possible, is applied in practice. The various experiments made on boilers, with regard to the evaporative power of coal, have not given very uniform results. Smeaton, in 1772, with one

* The coefficient for the latent heat of steam at 212° is generally taken at 1000°, but the above number is from the recent experiments of Regnault on this subject, as given in Table I.

TABLE VI.—*Showing the Actual Duty, and that which is theoretically possible, of the Coals examined.*

Name or Locality of Coal.	Actual number of lbs. Water converted into Steam by 1 lb. of Coal.—Practical.	Number of lbs. of Water convertible into Steam by the Coke left by the Coal.—Theoretical.	Number of lbs. of Water convertible into Steam by the Carbon of the Coal.—Theoretical.	Number of lbs. of Water convertible into Steam by the Hydrogen of the Coal.—Theoretical.	Total Number of lbs. of Water convertible into Steam by 1 lb. of Coal.—Theoretical.	Actual force generated, or the number of lbs. which 1 lb. of the Coal could raise to the height of 1 foot.—Calculated from heat obtained.	Force capable of being generated, or number of lbs. which could be raised to the height of 1 foot, by 1 lb. of Coal.—Theoretical.	Amount of Ammonia corresponding to the Nitrogen contained in Coal.	Amount of Sulphate of Ammonia corresponding to the Nitrogen contained in Coal.
	A.	B.	C.	D.	E.	F.	G.	H.	I.
Graigola	9·35	11·301	11·660	1·903	13·563	7,060,908	10,242,471	0·497	1·932
Anthracite, Jones, Aubrey, and Co.	9·46	12·554	12·563	2·030	14·593	7,143,978	11,020,303	0·225	0·990
Oldcastle Fiery Vein	8·94	10·601	12·046	2·890	14·936	6,751,285	11,279,329	1·590	6·175
Ward's Fiery Vein	9·40	..	12·072	2·542	14·614	7,098,667	11,036,162	1·238	4·808
Binea	9·94	11·560	12·181	2·912	15·093	7,506,463	11,397,892	1·586	6·741
Llangennock	8·86	10·599	11·741	2·519	14·260	6,690,871	10,768,829	1·299	5·044
Pentrepoth	8·72	10·873	12·189	2·649	14·838	6,585,146	11,205,322	0·218	0·848
Pentrefelin	6·36	10·841	11·749	2·038	13·787	4,802,928	10,411,630	Trace.	..
Powell's Duffryn	10·15	11·134	12·126	2·966	15·092	7,664,295	11,397,137	1·76	6·835
Mynydd Newydd	9·52	9·831	11·463	3·441	14·904	7,189,288	11,255,163	1·808	7·340
Three-quarter Rock Vein	8·84	7·081	10·325	2·781	13·106	6,675,768	9,897,355	1·299	5·044
Cwm Frood Rock Vein	8·70	8·628	11·300	3·488	14·788	6,570,043	11,167,563	1·347	5·232
Cwm Nanty-Gros	8·42	8·243	10·767	3·165	13·932	6,358,593	10,521,131	1·919	7·448
Resolven	9·53	10·234	10·899	3·072	13·971	7,196,840	10,550,583	1·675	6·505
Pontypool	7·47	8·144	11·088	3·207	14·295	5,641,175	10,795,260	1·639	6·364
Bedwas	9·79	8·897	11·075	3·766	14·841	7,393,186	11,207,587	1·748	6·788
Ebbw Vale	10·21	10·441	12·335	3·300	15·635	7,710,361	11,025,198	2·622	10·182
Porthmawr Rock Vein	7·53	6·647	10·263	2·548	12·811	5,686,485	9,674,577	1·554	6·033
Coleshill	8·0	6·468	10·145	2·654	12·799	6,041,419	9,665,515	1·785	6·930
Dalkeith Jewel Seam	7·08	6·239	10·242	2·071	12·313	5,346,655	9,298,499	1·214	0·471
,, Coronation	7·71	6·924	10·570	2·202	12·772	5,822,417	9,645,125	Trace.	..
Wallsend Elgin	8·46	6·560	10·454	2·968	13·422	6,388,800	10,135,991	1·712	6·647
Fordel Splint	7·56	6·560	10·933	2·884	13·817	5,709,141	10,434,286	1·372	5·327
Grangemouth	7·40	7·292	10·970	2·722	13·692	5,588,312	10,339,888	1·639	6·364
Broomhill	7·30	7·711	11·225	3·638	14·863	5,512,795	11,224,201	2·234	8·674
Park End, Lydney	8·52	6·567	10·101	3·156	13·257	6,434,111	10,011,386	1·477	9·617
Slievardagh (Irish)	9·85	10·895	10·995	1·487	12·482	7,438,497	9,426,124	0·279	1·084
Formosa Island	..	..	10·752	2·801	13·553	..	10,234,919	0·777	3·017
Borneo (Labuan kind)	..	..	8·864	1·388	10·252	..	7,742,078	0·977	3·771
,, 3 feet seam	..	..	7·461	1·295	8·756	..	6,612,333	1·132	4·620
,, 11 ,,	..	..	9·652	1·948	11·600	..	8,760,057	0·813	3·158
Wylam's Patent Fuel	8·92	8·378	11·186	3·145	14·331	6,736,182	10,822,447	2·040	7·920
Warlich's ,,	10·36	11·292	12·368	3·596	15·964	7,823,637	12,055,652	Trace.	..
Bell's ,,	8·53	9·168	12·074	3·343	15·417	6,441,663	11,642,569	0·983	3·818

pound of Newcastle coal, evaporated 7·88 lbs. of water from 212°; Watt, in 1788, came to the conclusion that 8·62 lbs. of water might be evaporated by the same quantity of coal; and later (in 1840), Wicksteed found that 1 lb. of Merthyr coal could be made to evaporate 9·493 lbs. of water from 80°, which is equal to 10·746 lbs. from 212°. In some experiments made on the boiler of the Loam's engine, at the United Mines, in Cornwall, each pound of coal was found, by a trial of six months, to evaporate 10·29 lbs. of water from 212°, this being the reduction of the result given, viz., that 234,210 cubic feet of water at 102° were evaporated by 700 tons of coal. Statements have indeed been made that 14 lbs. of water have been evaporated by 1 lb. of coal burned in Cornish boilers; but as this is the utmost quantity theo-

retically possible, it is difficult to conceive that it has been realized in practice, even in the best-constructed steam engines.

To ascertain how far our boiler was inferior to Cornish boilers, as principally from its small size and less efficient coating it was likely to prove, we requested Mr. Phillips to make some experiments on one of the best engines in Cornwall, the results of which are given in the Appendix, Section II. It was found by these experiments, that 11·42 lbs. of water were evaporated by every pound of Welsh coal corresponding in composition to that of Mynydd Newydd ; or, in other words, that improved Cornish boilers on a large scale may be assumed to have a superiority of nearly 20 per cent. over that used in these experiments. As the results stated in this Report are only relative, the comparison is not affected by this difference.

We have anxiously looked to the application of these experiments to the different varieties of patent fuel, but we have not been able to carry out our observations in this direction to the extent we could have desired, from our inability to procure patent fuels in sufficient number, although our applications to the patentees have been numerous. Three varieties have been already examined, viz., those manufactured under the patents of Messrs. Wylam, Warlich, and Bell, and the results are given in the Tables. The varieties of patent fuel are generally made up in the shape of bricks, and are therefore well adapted for stowage ; so that, though the specific gravity of patent fuels is lower than that of ordinary coals, from their shape and mechanical structure, there are very few coals which could be stowed in a smaller space per ton. While we look to the different varieties of patent fuel as of the highest importance, and, from their facility of stowage, as being peculiarly adapted for naval purposes, and perhaps even destined to supersede ordinary coal, at the same time, the greater part do not appear to be manufactured with a proper regard to the conditions required for war steamers. It is usual to mix bituminous or tarry matter with bituminous coal, and from this compound to make the fuel. An assimilation to the best steam coals would indicate, however, the very reverse process, and point to the mixture of a more anthracitic coal with the bituminous cement. As the greater part is at present made, it is almost impossible to prevent the emission of dense opaque smoke, a circumstance extremely inconvenient to ships of war, as betraying their position at a distance at times when it is desirable to conceal it. Besides this and other inconveniences, the very bituminous varieties are not well suited to hot climates, and are as liable to spontaneous combustion as certain kinds of coal. To avoid these inconveniences, some kinds of patent fuels have been subjected to a sort of coking, and thus, in a great measure, obtain the desired conditions

There is little doubt, however, that notwithstanding the large number of patents in operation for the manufacture of fuel, its value for the purposes of war steamers might be much enhanced by its preparation being specially directed to this object. It will be seen, by reference to Table II., that the three patent fuels examined rank among the highest results obtained. Should it be desirable to continue this inquiry, we conceive that it would be advantageous to pay especial attention to this subject, by experimenting upon proper mixtures of different coals. Even anthracite may be introduced into such mixtures with advantage.

It is of much importance, in an economical inquiry on coals, to obtain exact information as to the effects likely to be produced upon them by stowage, and continued exposure to high temperature, not only as regards their deterioration, but also as to the emission of dangerous gases by their progressive changes.

The retention of coal in iron bunkers, if these are likely to be influenced by moisture, and especially when by any accident wetted with sea-water, will cause a speedy corrosion of the iron, with a rapidity proportionate to its more or less efficient protection from corroding influences. This corrosion seems due to the action of carbon or coal forming with the iron a voltaic couple, and thus promoting oxidation. The action is similar to that of the tubercular concretions which appear on the inside of iron water-pipes, when a piece of carbon, not chemically combined with the metal, and in contact with saline waters, produces a speedy corrosion. Where the "make" of iron shows it to be liable to be thus corroded, a mechanical protection is generally found sufficient. This is sometimes given by Roman cement, by a lining of wood, or by a drying oil driven into the pores of the iron under great pressure.

Recent researches on the gases evolved from coal prove that carbonic acid and nitrogen are constantly mixed with the inflammable portion, showing that the coal must still be uniting with the oxygen of the atmosphere, and entering into further decay.

Decay is merely a combustion proceeding without flame, and is always attended with the production of heat. The gas evolved during the progress of decay, in free air, consists principally of carbonic acid, a gas very injurious to animal life. It is well known that this change in coal proceeds more rapidly at an elevated temperature, and therefore is liable to take place in hot climates. Dryness is unfavourable to the change, while moisture causes it to proceed with rapidity. When sulphur or iron pyrites (a compound of sulphur and iron) is present in considerable quantity in a coal still changing under the action of the atmosphere, a second powerful heating cause is introduced, and both acting together may produce what is termed *spontaneous combustion.*

The latter cause is in itself sufficient, if there be an unusual proportion of sulphur or iron pyrites present.

The best method of prevention, in all such cases, is to ensure perfect dryness in the coals when they are stowed away, and to select a variety of fuel not liable to the progressive decomposition to which allusion has been made. This is, however, a subject of so much importance to the Steam Navy, that it continues to receive our careful attention; and, beyond these general recommendations, it would be premature to offer any decided course for adoption, from the present limited series of observations.

Several varieties of coal were transmitted from Formosa and from Borneo, for analysis, the results of which are contained in the accompanying table. The quantity of each kind was so small, that no experiments could be made on their evaporative value. We extract from the preceding table the following results:—

Name.	Carbon.	Hydrogen.	Nitrogen.	Sulphur.	Oxygen.	Ashes.	Specific Gravity.
Formosa Island . .	78·26	5·70	0·64	0·49	10·95	3·96	1·24
Borneo, Labuan kind	64·52	4·74	0·80	1·45	20·75	7·74	1·28
,, 3 feet seam .	54·31	5·03	0·98	1·14	24·22	14·32	1·37
,, 11 feet seam.	70·33	5·41	0·67	1·17	19·19	3·23	1·21

It may be desirable to sum up, in a few words, some of the principal points alluded to in the previous parts of this Report. It has been shown that the true practical value of coals for steam purposes depends upon a combination of qualities which could only be elicited by carefully and properly continued experiments. Their qualities, so far as regards steam-ships of war, may be stated as follows:—

1. The fuel should burn so that steam may be raised in a short period, if this be desired; in other words, it should be able to produce a quick action.
2. It should possess high evaporative power, that is, be capable of converting much water into steam, with a small consumption of coal.
3. It should not be bituminous, lest so much smoke be generated as to betray the position of ships of war when it is desirable that this should be concealed.
4. It should possess considerable cohesion of its particles, so that it may not be broken into too small fragments by the constant attrition which it may experience in the vessel.
5. It should combine a considerable density with such mechanical structure that it may easily be stowed away in small space;

a condition which, in coals of equal evaporative values, often involves a difference of more than 20 per cent.

6. It should be free from any considerable quantity of sulphur, and should not progressively decay, both of which circumstances render it liable to spontaneous combustion.

It never happens that all these conditions are united in one coal. To take an instance, anthracite has very high evaporative power, but not being easily ignited, is not suited for quick action; it has great cohesion in its particles, and is not easily broken up by attrition, but it is not a caking coal, and therefore would not cohere in the furnace when the ship rolled in a gale of wind; it emits no smoke, but from the intensity of its combustion causes the iron of the bars and boilers to oxidate or waste away rapidly. Thus, then, with some pre-eminent advantages, it has disadvantages which, under ordinary circumstances, preclude its use. The conditions above alluded to may, however, often be united in fuels artificially prepared from coals possessing these various qualities, somewhat in the manner of what are usually termed "patent fuels," and we have recommended that experiments should be made with this object, especially directed to the wants of the Steam Navy. Whilst we look with this view to artificial fuel as being of special importance, it was quite necessary to obtain a knowledge of coals in different districts, and, for this purpose, Wales was first selected for examination, as producing coals of all kinds varying from bituminous to anthracitic.

While the experiments devised to obtain information on the various points alluded to have been conducted with all proper precaution, in order that constant *comparative* results might be procured, they have not been overburdened with scientific corrections, which might have been necessary to obtain absolute truth, but would have introduced an affectation of accuracy where practical results only were required; to the latter, therefore, this Report has been principally confined. The Report has been so divided as to bring the results together without complicating them with the details of the properties peculiar to each coal, information on which is of the highest value. Hence in Table II., the practical results of the experiments are brought together, while the equally practical information regarding each coal, its local position, the port from whence it is shipped, its price, its peculiar characteristics in burning, the greater or less quantity of smoke and of ashes which it produces, the description of the coal, its geological position, and other similar points of importance in practice, are detailed for each coal in Section II. of the Appendix.

The composition and specific gravities of the coals, and the quantity

of coke which they produce, are given in Table III., not only as a means for their future identification, but also as a standard of quality, with relation to which particular kinds may be purchased. The amount of sulphur as given in this table, is of considerable importance in determining the value of the coal for naval purposes, as a means of avoiding the risk of spontaneous combustion.

The heating values of the coal are given in Table IV., as a simpler and more ready method of identification, enabling the purchaser to insure the sample of the coal of a certain heating value.

Table V. shows how the inquiry might easily be extended to other branches of national industry, especially to gas manufactures, but is only adduced as an example of its applicability for such purposes.

Table VI. is principally for the purpose of showing that the actual duty obtained by the combustion of coal in the best-applied practice is only a small part of that which the fuel is capable of producing, and is brought forward as an inducement to improvement in the construction of the furnaces and boilers employed for the production of steam. Attention is also drawn in this table to the great loss which agriculture suffers by the waste of ammonia always produced in the coking of coal, and which might to a great extent be economised by very simple adjustments to the ovens used in coking. The economy and consequent reduction of price in the ammoniacal salts, by preventing this great loss in a material so well fitted to aid increased production in land, would be a great boon to agriculture. Suggestions have also been thrown out as to the more economical application of fuel for domestic and for manufacturing purposes.

In concluding this First Report, we cannot refrain from drawing attention to the kind manner in which we have been assisted by various public and private institutions and companies, without whose aid the expenses of the inquiry would have been materially increased.

The College for Civil Engineers, at Putney, afforded us, gratuitously, ground upon which to erect the boilers, and a house and yard for the stowage of the coals. The laboratory and workshops of the college were also placed at the disposal of the investigation, and have constantly been used. The Principal of the College, the Rev. Mr. Cowie, on all occasions, afforded his valuable aid in the prosecution of the experiments.

The owners of the collieries, from which the coals were obtained, furnished them free of expense; and the Great Western Railway Company, with an enlightened liberality, carried those sent to Bristol on their railway to London without charge. To Mr. George Rennie, the eminent engineer, the inquiry is specially indebted. This gentleman not only lent a tubular boiler, gratuitously, to enable the experi-

ments to be repeated on this kind of boiler, but he also offered his premises for the prosecution of the experiments, which offer was accepted, until the larger space at the College for Civil Engineers was placed at the disposal of the investigation.

Such ready and liberal co-operation of the public shows their appreciation of the important practical results which may be expected from these experiments. Seeing the present effective state of the boilers and other apparatus erected at Putney, consequently, that the expenditure on this account has been incurred, and that any further charges for continuing these investigations would chiefly consist of payments of salaries to the persons employed as assistants, we would suggest for consideration, that these experiments may be extended to the coals of other districts than those the coals from which have been examined, and that the needful expenditure may be sanctioned for one or two years more. Should this be deemed advisable, we should anticipate that a most important body of information would be accumulated, alike important to the naval service and the public at large.

We have the honour to be, &c.,

H. T. De La Beche.
Lyon Playfair.

APPENDIX.

Section I. — *Description of Boiler and Apparatus, &c.* By Professor Wilson, F.R.S.E., and Mr. J. Arthur Phillips.

General arrangement of Apparatus for testing the evaporating power of the Coals.

The boiler-house (marked A on the plan, plate No. 1), which was erected for the purpose of carrying out the experiments, is built with one end against the side of the building (B) employed as the laboratory and chemical lecture-room of the College for Civil Engineers, forming a rectangular building, 35 feet in length and 16 ft. 6 in. in breadth, covered with a "lean-to," or sloping roof, the height of the wall on the lowest side being about 12 feet above the floor line. A room (C), occupying the angle between a portion of the side of the boiler-house and the remaining part of the side of the laboratory, and communicating with both by means of doors, contains the barometer and other apparatus employed in the analysis of the gases, and formed a convenient place for the determination of the combustible matter in the residua, the density of the coals, and other purposes more strictly connected with the chemical part of the investigation.

The brickwork of the boiler is built against the end wall farthest removed from the laboratory, its width being 7 feet 8 inches, and length 15 feet; the side is separated from one side wall of the boiler-house by an interval of 18 inches, and from the other, consequently, by a space of 6 feet. This space of 18 inches prevents loss of heat from the boilers by conduction through the external wall, and furnishes ready means of access to the base of the chimney (D), which occupies the corner of the building at one extremity. A slate roof covers the building, the slates being laid on a substantial layer of asphalted felting, which serves the double purpose of preventing the communication of heat from the air in the building to the slates, and also down currents of cold air from outside, through the spaces round their edges.

On the other angle of the building, and at the distance of its width from the chimney, are placed the tanks (E, F) which supply the boiler with water.

They are made of wrought-iron plates riveted together, and are placed outside the roof on the wall, the cast-iron pipe (G), which supplies them with water, being brought up inside the building in the angle of the wall, to defend it from the action of the frost. The extremity of the pipe is furnished with the means of directing the flow of water into either tank at pleasure, and a two-way cock, *b*, connected with the tanks, directs in a similar way the supply from them to the boiler. The cock *b′* on the feed-pipe, a short distance below this, regulates the quantity of water admitted to the boiler.

The boiler is cylindrical in form, 12 feet in length and 4 feet in diameter,

having flat ends, with an internal flue 2 feet 6 inches in diameter, in which, at one end, the grate is placed, forming the arrangement usually known by the name of the "Cornish boiler." The flues are on the plan known technically by the name of "split" or "bridle" draft, in which the column of heated air, after leaving the fire, passes through the internal flue to the rear end of the boiler, where it divides, returning along the outside of the boiler on both sides to the front: the two branches, which are each 2 feet 6 inches deep, then turn down at right angles to their former course, and uniting under the boiler in the bottom flue, which is 2 feet 6 inches wide, traverse its whole length again, and finally enter the base of the chimney after exposing, during a course of about 36 feet, an area of 197·6 square feet of boiler surface to the heating action.

In the horizontal part of the flue at K, just before entering the chimney, a damper is placed, sliding vertically in a cast-iron frame, which is worked by means of a rod passing through a stuffing-box and attached to a cord, K′, carried over two pullies, and furnished with a balance-weight, so that a person standing near the fire-door can regulate the amount of draught with great convenience.

The chimney, its internal dimensions being 13½ inches by 13½, and consequently having a sectional area of 182¼ square inches, is carried up in brick-work, with a stone coping, to a height of 29 feet 6 inches above the base of the flue; a wrought-iron chimney-pot succeeds this, making the whole height 35 feet 6 inches.

Apertures were made in the chimney at D′ D″, about 6 feet from its base, for the purposes of making observations on the temperature of the currents, and of obtaining samples of the gases for analysis. At the end of each of the side flues, and at the base of the chimney, openings were made through the external wall for the purpose of drawing out the soot at the end of each set of experiments. The floor of the flues is laid in fire-tiles to facilitate its removal, and the apertures at the end are closed and loss of heat prevented, when the furnace is in action, by means of stone doors 4 inches thick, then an interval for air, about 1 inch thick, and finally cast-iron hanging doors lined with fire-clay.

The fire-grate is 2 feet 6 inches wide, and 2 feet long, thus giving an area of 5 square feet of grate surface; the bars are ¾ inch in thickness, with ½ inch spaces between them. In the front end of the grate, near the fire-door, is an iron plate, for the purpose of gradually heating the bituminous and anthracitic coals, which is 10 inches wide, and slopes down to the grate, and behind this is another plate 8 inches wide, which slopes upwards to the fire-door, contracting in its width to 15 inches, which is the width of the aperture for the introduction of fuel.

The doors * used for closing the entrances to the grate and ash-pit are of a novel construction, and are well adapted for preventing loss of heat, regulating the direct supply of air to the fire, and the convenient application of fuel.

* The fire-doors were made under the direction of the patentee, Mr. Sylvester, who liberally remitted his patent right on the occasion of this investigation.

The arrangement will be understood from the following description:—

c, *d* is a large cast-iron plate let into the brick-work, and having four projecting brackets, *ee*, *ff*, in which are secured the ends of stout cylindrical bars, which are to carry the doors. The apertures to the grate and ash-pit are surrounded with an iron rim, or edge, about ½ inch wide, the lower part being continued backward along the plate, forming a kind of guide, *g*, *h*. The fire-door, which exactly resembles the ash-pit door, consists of a rectangular cast-iron box, having its edge ground so as to fit accurately the iron rim before described, and the interior is filled with, first, a layer of fire-brick, then a space for air, and then another thickness of fire-brick, which effectually prevents loss of heat. The top of the door has projectiug ledges, forming the cheeks for two friction-wheels, *l*, *l*, which run on the cylindrical bar already mentioned, so that, when the door is drawn sideways by means of the handle, *k*, at its back, the wheels roll along the bar, the lower part of the door sliding, at the same time, along the ledge closely or guide, *g*.

The two sides of the aperture are sloped gradually so as, with the lower edge, to project more at bottom than at the top; this causes the weight of the door to act in keeping the surfaces in contact.

There are three safety-valves (marked N on plan, plate 1), one of which is loaded, directly having an area of 5·4 square inches, and two smaller steelyard valves, each having an area of 2·07 square inches. In the experiments, the boiler was worked the first two days with a pressure of 1 lb. per square inch, and generally on the third day with a pressure of 3 lbs on the inch.

The thickness of brickwork at the crown of the boiler is 4½ inches, and the walls were brought up on a level with it, and then covered with a paving of 3 inch York landing, thus forming a large platform, affording convenient access to the different thermometers and apparatus.

The brickwork was very carefully executed, being laid with hoop-iron bond, and every course well grouted so as to insure sound work, and entirely to prevent the passage of the external air into the flues. Openings were made into the side flues at H, I, in about the middle of their length, in which were fixed iron tubes, closed at the lower end, and containing oil, in which the thermometers were placed for giving the temperatures; a similar tube was inserted at *k* in the base of the chimney, and another in the boiler at L, to give the initial temperature of the water in it.

For drawing samples of the gases, the products of the combustion of the coals, a simple arrangement was adopted. A series of glass tubes, narrowed at each end, were connected together by caoutchouc tubes, and introduced into the iron tube of the chimney. The other end of the system of tubes was connected with a gas-holder filled with water. On opening the stop-cock of the gas-holder, connection was established between the chimney and the former, and a current of the chimney gases flowed through the tubes. After this had continued for some minutes, so as to expel the air, the caoutchouc joints were tied and the tubes removed. Their contracted parts were afterwards sealed by a blow-pipe's flame, and laid aside for analysis.

The method adopted for analysing the products of combustion belongs more particularly to the chemical part of the investigation, and will not, therefore, be described in this place.

The dew-point was taken at about the middle of each day's experiment, by means of a Daniell's dew-point hygrometer. The situation chosen for the observation was at the end of the boiler-house, farthest removed from the boiler, and the instrument was placed on a small wooden ledge, fixed against the wall at such a height as to bring the bulb of the instrument on a level with the observer's eye.

The two observations seldom gave a difference of 1°, in most cases much less.

Method of testing the cohesive power of the Coals.

For this purpose a wooden cylinder was employed 3 feet in diameter and about 4 feet long, each end having a bearing or gudgeon attached to it, on which the whole was made slowly to revolve. In the interior, three shelves tending to the axis were fixed, each being six inches in width: they were for the purpose of forming a lodgment for the coals, and of carrying them up towards the top of the cylinder during its revolution, thus insuring a certain amount of fall. An aperture was made at one end for the purpose of putting in the coals and for taking them out, which was closed, and rendered perfectly dust-tight by an oak door, firmly secured by an iron bar and staple. The cylinder was supported by a tressle at one end, the other gudgeon resting on a block let into the wall, and motion was communicated by a band passing round its circumference.

The coals to be tested were first broken to the size always employed in our experiments on their evaporating power, and then thrown on a sieve, the meshes of which were one inch square. Of the coals left on the sieve 100 lbs. were taken and put into the cylinder, which was then turned a certain number of times.

The whole was then allowed to rest a short time for the dust to settle, when the door was opened, and the coals again thrown on the same sieve, and the weight of coals remaining in it gave the per centage of large coals found in the tables.

The values given in the tables are the mean of two trials with each coal, with 50 revolutions.

The box in which the coals were weighed for supplying the fire, and also to obtain the economic weight, was 2 feet long, 2 feet wide, and 1 foot 6 inches deep, and consequently contained six cubic feet. The large coals were reduced to pieces, not exceeding 1lb. weight previous to weighing, and this was the maximum size employed throughout the experiments.

Method of conducting the Experiments.

Having described the boiler and apparatus connected with it, we have now to state the course pursued in conducting the experiments.

Let us suppose the water in the boiler to be cold, and to stand about 1 inch

below the normal level. The fire was lighted, and any coals that might be convenient employed to get up the steam in the afternoon of the day preceding the commencement of the experiments. As soon as this was the case, the fire was allowed to burn out, when the fire and ashpit doors, as well as the damper, were closed.

The next morning, the first thing done was to open the safety valve, to equalise the external and and internal pressures, and then sufficient water was let down from the tanks to raise that in the boiler to the normal level.

The depth of the water in the tanks was then gauged, and the first observation of its temperature made. The ashes, cinders, and soot were next cleared out, and after noting the temperature of the water in the boiler, the fire was lighted with a weighed portion of wood, and the exact time was then observed.

The coals were then gradually added till the fire was of the proper size and form. The form of fire was slightly varied according to the kind of coal employed, our object being to burn the coal to the best advantage, with as little smoke appearing at the chimney top as possible.

The observations of the temperatures of the two side and escape flues, and of the water in the tanks, then succeeded each other at regular intervals of about an hour each.

When the steam raised the safety-valve, the time was observed and entered under the heading "Steam up." The damper was adjusted as soon as the fire was sufficiently established, and was not disturbed during the day, except under peculiar circumstances.

When by evaporation the water had sunk about 1 inch below the normal level, the deficiency was supplied from the tanks above: this was the plan pursued at first, but latterly we found it more convenient to allow the water to flow in continuously so as to maintain the water in the boiler at a constant level, which was easily accomplished after a little experience.

In the management of the fire, care was taken to supply the coals in pieces not exceeding 1 lb. in weight, and in quantities of not more than one or two shovel's-full at a time, spread evenly on the fire, except in the cases of the anthracite and some of the bituminous coals. In the case of the anthracite, it was found that the sudden application of heat caused the pieces to split, and fall through the bars, and hence a gradual heating on the dead plate was beneficial. With the bituminous coals a preparatory process of partial coking on the dead plate prevented them from caking in the fire, which would have impeded the passage of air through the grate, besides giving better opportunity for burning the smoke and gases, by passing them over a large surface of ignited fuel.

The duration of the experiment was reckoned from the time the steam was up to that of the last application of fuel, after which the fire was allowed gradually to burn out, when the damper, and furnace, and ashpit doors were closed.

During the day the ashes were thrown up in small quantities from time to time when the fire was burning clear and well.

The weight of coals consumed was then ascertained, by deducting the weight left from the gross weight provided for the day's trial, and the experiment terminated.

The next morning, when the level of the water in the boiler was adjusted by turning down a supply from the tanks, their depth was gauged, and the quantity evaporated the previous day was thus ascertained. The ashes and cinders were then removed, the clinkers if present separated, and the weight of each taken. The soot was cleared out at the end of the last day's experiment, and the total weight recorded, which divided by the number of trials gave the average weight.

Samples of the ashes, cinders, and soot were then put aside in bottles, for the purpose of ascertaining the per centage of combustible matter present in the residue.

The barometer was observed at about 11 o'clock in the day, being generally about two hours after the steam was up.

Method of estimating the quantity of Combustible Matter in the residue.

This consisted in heating the powdered substance in a stream of oxygen gas, by which the organic matter was dissipated chiefly as carbonic acid and water, and estimating the loss as combustible matter.

For this purpose a piece of German glass tube, 4 inches long and half an inch in diameter, was drawn out at one end to a small orifice, which was then loosely obstructed by a piece of asbestos. It was then weighed, and again after the introduction of a small quantity of the substance; after which it was attached to the cock of an ordinary gasholder filled with oxygen, by means of a piece of glass tube and a cork.

A lamp was next placed under the tube, and the powder in it gradually heated up to incipient redness; when this was the case, the cock was opened, and a slow current of oxygen was made to pass over the heated material. Combustion then commenced, and was continued till the organic matter was entirely consumed; the gases escaping at the extremity of the tube, and the asbestos at the same time preventing the possibility of any of the powder from being carried away mechanically by the current; the cock was then closed, and the tube allowed to cool. When cold it was weighed, and from the loss it was easy to calculate the per centage of combustible matter which is given in the tables.

It was found advantageous not to reduce the ashes, &c., to a very fine powder, for when in that state the high temperature caused the fusion of some of the inorganic substances, which prevented the complete combustion of the organic matters, by defending them from the action of the stream of oxygen.

Method for obtaining Water of uniform temperature in Boiler.

Considerable difficulty had been experienced during the former part of the investigation in obtaining the mean temperature of the water in the boiler at the beginning and end of an experiment; arising from the normal level being

established by letting down water to the bottom of the boiler by means of the pipe E′, E′, E′, Plate II., and cold water being denser than hot, the cold water remained at the lower part of the boiler without mixing with that it already contained.

Experiments on this difference of temperature were frequently made, by reading off the thermometer L, and at the same time placing another thermometer in a stream of water issuing from the cock X, the water being first allowed to flow some considerable time in order that the pipe should become heated, and therefore not materially affect the temperature of the water flowing through it. By this means these two temperatures were found to vary on an average about 70°, which would make a considerable difference between the real and apparent weight of the water contained in the boiler; and as this is one of the elements employed in calculating the evaporative value of the coals experimented on, it was thought important to be able to find the true mean temperature.

In order to do this, the mixing apparatus, P, Q, R, S, Plate II., was put up: it consists of a force-pump, P, by means of which water can be drawn from the bottom of the boiler, and, passing in direction of the arrows α, α, α, β, β, β', &c., be distributed on the top by means of the perforated extremities of the tubes T, T, T. In another position of the three and four-way cocks, R and S, the water passes directly from the tanks to the bottom of the boiler, as before the apparatus was put up; whilst by a third modification in the position of the plugs of the cocks R and S, the water can be made to flow directly on the top of the boiler from the tanks E, F, as shown by the arrows γ, γ, β, β.

This apparatus was after its erection used at the beginning and end of each experiment. The method of employing it was as follows:—

Supposing an experiment to have been made the previous day, the first thing done on arriving in the morning was to turn the cocks R and S in a proper position, and then, by means of the pump P, force water from the bottom of the boiler on the top at T, T, T, in the direction of the arrows α, α, β, β, β', $'\beta$, β'. This operation generally lasted ten minutes; when the cocks R and S being turned in another position, the normal level was restored by letting down water from the tanks in the direction of the arrows γ, γ, β, β, β', β, $'\beta'$, when the cold water flowing from the apertures T, T, T, being denser than that contained in the boiler, falls to the bottom, but in doing so abstracts heat from the warm water through which it passes until the equilibrium is restored; the temperature is then read off by means of the thermometer L, and the cocks R and S turned in such a position that the water shall flow directly into the bottom of the boiler, and in the direction of the arrows γ, γ, γ, in which position they remain during the whole experiment. It is also necessary to shut the cocks T, T, T, in order to prevent the condensation of steam in the apparatus, and cut off all communication with the boiler. By this means, the temperature of the water in the boiler becomes perfectly uniform throughout; for on placing a thermometer after the operation in a stream of water flowing from the cock X, a difference of two degrees between it and the thermometer

L was rarely observed. These operations were repeated every morning during the progress of the experiments, as also on that of the fourth day, when the series of experiments was completed. The last temperature is used in the calculations of the work done on the third day, whilst in the other cases the final temperature of one day is evidently the initial temperature of the succeeding.

It might perhaps appear that a considerable portion of heat must be lost by radiation from the tubes, Q, Q, Q, and Q′, Q′, Q′, during the process of pumping; but every precaution having been taken to prevent this, by covering them with felt, &c., it was sufficiently reduced as to produce no sensible effect on the results.

The cock X is also used for blowing off the water in order to cleanse the boiler; for since the water with which it is supplied contains on an average 20 grains of fixed matters in the gallon, and from three to four hundred gallons of water were daily blown off, the boiler becomes rapidly coated with a residue which would interfere with and modify the experiments, and therefore requires frequent removal.*

Another inconvenience which occurred during the former portion of the investigation arose from the difficulty of measuring with sufficient accuracy the quantity of water let down from the tanks during an experiment; as well as from the trouble of having to calculate from the measurement made each day the quantity used. In order to obviate this and render the apparatus more convenient, the water gauges, *e* and *f*, Plate III., were fitted to the tanks. They consist of bent glass tubes $j' \, j'$, connected with the tanks by means of the stop-cocks, $j''' \, j'''$, and were graduated by filling the tanks with water at the temperature of 70° Fah^{t}., and then weighing it out and marking the level on the tube after each weighing by means of a scratching diamond.

At each successive weighing, a hundred pounds were drawn off, and subdivisions made on the scale by measurement, as between these limits no errors of importance could occur. These graduations having been made at 70° Fah^{t}., it was taken as the normal temperature, and a Table formed, which will be found in another part of the Report, for the purpose of correcting the indications of the water gauges whenever the thermometers of the tanks do not indicate that temperature.

* The analysis of this residue gave the following results:—

Carbonate of Lime	59·75
Sulphate ,,	6·00
Phosphate ,,	3·00
Silica	9·75
Peroxide of Iron	6·25
Carbonate of Magnesia	2·00
Alumina	2·87
Organic matter	10·35
Alkaline Chlorides	Trace
	99·97

J. A. P.

Section II.—*Experiments on the Evaporative Power of the Coals.* By Professor Wilson and Mr. W. J. Kingsbury.

Museum of Economic Geology,
August 20, 1846.

Sir,

I beg to inform you that, in accordance with your instructions, I have been through the South Wales district, and have visited all the shipping ports, for the purpose of making myself acquainted with, and obtaining samples of those coals most approved of, and best adapted for steam purposes.

As the details of my report will necessarily be somewhat voluminous, I will now merely give you an outline of what I have done in the matter:—

I commenced my inquiry at Newport, where I found several coals well adapted for steam purposes; the principal were the Risca Veins, the Porthmawr, Cwm Brane, Tredegar Company's, the Duffryn, the Varleg, and others. I then proceeded to Cardiff, where I found Yniscynon, Merthyr, and Blaengwawr, the only coals shipped as steam coals: but there are others having a high repute as coking coals of first quality, which I think might, with much advantage, be included in our researches. At Porth Cawl, the next shipping port, there are at present only two sorts shipped, the Bryn-ddu and the Bethvos, both of excellent quality, the first being of a bituminous nature. At Tailbach and Port Talbot, the Rock Vawr Vein of Messrs. Vivian, with two others belonging to the Governor and Company of Copper Mines, appear to be the only coals worth notice.

There are two coals shipped at Briton Ferry, but not suitable for steam purposes.

At Neath I found several sorts sold as steam coals; the Bryndowy-Pwllfaron, Tyr Edemed, Abbey Graigola, Resolven, which, with several others, I have selected as best adapted for the purposes of this investigation. At Swansea, also, I met with several free burning coals, amongst which I selected the Forest Graigola, the Pentrepoth, the Graigola Company's, Colebrook Dale Company's, with a few others of good repute as steam coals.

The limit of my visit was Llanelly, where I also found several sorts of coal suitable for our purpose, and at the same time selected some samples from those coals usually considered unfit for steam purposes, as being too anthracitic. The free burning coals were the Llangenech, the Binea, Oldcastle Vein, Ward's Vein, and Webb's, with the anthracitic coals of the Gilly Ceidrim and Garnant mines. I think these last samples will be sufficient for our purposes, but that it will be very desirable to obtain also samples of those further advanced beds mined in the county of Pembroke. We shall then be in a position to determine the relative character of the four different conditions of the Welsh coal-field, viz., the bituminous, transition, or free burning, the anthracite, and the pure anthracitic.

Throughout the whole of my survey I found, both on the part of the proprietors and their agents, the greatest readiness to afford information, and

desire to co-operate with us in this investigation, every one readily acknowledging its great importance to all parties concerned in the coal-trade of the country. The plan I pursued was to make myself acquainted with the coal-owners, explain to them the nature of this investigation, and invite them to furnish us with samples of their coals selected, subject to certain conditions which I have deemed it advisable to make, and which have met with perfect concurrence from all.

My stay in South Wales was limited to the shortest possible time, as I was anxious to return as speedily as possible, in order to get my boilers set, and the apparatus in proper working order.

Should it hereafter be deemed advisable to extend these researches to the various uses of coals in metallurgic and other manufacturing arts, I could then devote more time to the survey, and also obtain samples of those coals which, although well adapted for steam purposes, have nevertheless, from local disadvantages, not yet found their way into the market—of this description I am sure there will be found several sorts.

I have, &c.,

Sir H. T. De la Beche, London. (Signed) J. Wilson.

Pentrefelin Coal.

I hereby certify that the four casks, marked P.V., No. 1, contain a fair sample of the Pentrefelin coals, which were mined especially for the service of the " Admiralty Coals Investigation."—J. E. Morrice, *Agent for Swansea Coal Company.*

This coal is obtained near to the village, and in the parish, of Llangevelach, and is generally known by the name of the Clyndie, or 5-foot vein, and is worked at a depth from the surface of about 360 feet. The seam is about 4½ feet thick, and very regular throughout. The character of the subjacent stratum appears to be a soft undercliff, with 5 feet of cliff over the coal, covered by a thick bed of hard sandstone. The dip of the bed is 3½ inches in the yard; the direction 13° S.W. It is a free burning coal, and is used chiefly at the copper smelting works in Swansea. The price through and through to the copper works is 41*s.* per 11 tons, being about 3*s.* 9*d.* per ton; if shipped as culm, the present price is 4*s.* 6*d.* The coal lies considerably north, and verges on the stone coal district; it makes very good culm for lime-burning. The sample of coal sent had been very loosely packed, and, being of a soft character, had become reduced into very small pieces, some even into a coarse powder. It has an indistinct fibrous structure with numerous horizontal plates of shaly matter, and also of a soft dark-coloured friable substance, chiefly along the line of bedding. A large part of the coal is made up of rectangular masses, which break up with a smooth, though not very bright, fracture. It is, however, a clean-looking coal, with but small quantities either of white substance or of iron pyrites.

Our remarks during the trials show that, owing to the extreme smallness

of the coal, there was great difficulty both in lighting the fire and in getting the steam up: the same cause, no doubt, affected the trials throughout, as the work done was very small in comparison with that of other coals. As the fire burnt up, a distinct hissing noise was heard, and, on opening the fire door, large quantities of ignited particles, presenting a bright scintillating appearance, were carried over the fire bridge, and passed into the flues.

On stoking the fire, a considerable quantity of unburnt coal slipped through the bars, which, on being again thrown up, increased the difficulty of getting a good fire. The quantity of cinders and ashes left was consequently very large.

——	December 7, 1st day.	December 8, 2nd day.
Fire lighted	8h. 15m.	8h. 20m.
Steam up	10h. 20m.	10h. 30m.
Weight of Wood used	10 lbs.	15 lbs.
Initial Temperature of Water in Boiler	162°	162°
Temperature of Water in Tanks	35°	37°
Barometer	..	..
Extremes of external Thermometer	..	..
Extremes of internal Thermometer	..	..
Dew-point	..	..
Area of Damper open	168 in.	168 in.
Weight of Coals consumed	311 lbs.	311 lbs.
Weight of Ashes left	27 lbs.	65 lbs.
Per centage of combustible matter in Ashes	64·8	..
Weight of Cinder left	46 lbs.	31 lbs.
Per centage of combustible matter in Cinder	30·87	..
Weight of Clinker in Cinder	4 lbs.	2·3 lbs.
Average weight of Soot in Flues	1·9 lbs.	..
Per centage of combustible matter in Soot	51·45	..
Weight of Water evaporated	1397 lbs.	1849 lbs.
Weight of Water evaporated from 212° by 1 lb. of Coals	6·36 lbs.	6·36 lbs.
Weight of Coals per hour for 1 square foot of grate surface	17·54 lbs.	7·99 lbs.
Duration of Experiment	8 hrs.	8hrs.
Specific gravity of Coal	1·358	..
Mean weight of cubic foot of Coal	66·16 lbs.	..
Economic weight or space occupied by 1 ton	33·85 c. f.	..
Cohesive power of Coal	52·7	..

Duffryn Coal.

I hereby certify that the casks of coal, marked in the margin of this certificate, contain a fair sample of the Duffryn steam coals, which were mined specially for the service of the "Admiralty Coals Investigation."—R. K. Jones, *Agent.*

The Duffryn steam coal is called the 4-feet vein, and is obtained in the valley of Aberdare, near Merthyr, in the county of Glamorgan. The depth of the pit is 288 feet, and the thickness of the vein is generally about 6 feet. It is worked in the form of stall and heading; the small and refuse is cast back, or gobbed in the stalls and waste; the large coal is filled into waggons,

containing about a ton each, and conveyed from the stalls or heading to the top of the pit. The overlying stratum is strong clod or rock, and the subjacent stratum is strong fire-clay and rock. The dip of the vein is 1 in 9, or 4 inches in the yard, and crops towards the north. It is described as a free-burning coal; and its principal markets are London, Liverpool, Southampton, Dublin, and Plymouth. The distance from the colliery to Cardiff, the shipping port, is 22 miles, to which there is conveyance by both railroad and canal. No current price is given in the return, which states "that the coal has been shipped largely to the West Indies, under contract with the Government, for steam purposes, and has also been sent to the Mediterranean and America, and has given much satisfaction."

This is a coal of rather a soft description, easily breaking up into small pieces with a bright appearance of fracture, but which is somewhat obscured by the apparent irregularity of its structure. It contains a considerable proportion of a white substance, but no iron pyrites were observed in it. Some portions of the coal, where the structure is well seen, show the lines of fibrous structure as perpendicular to the planes of deposition or bedding. Numerous very thin layers, of a soft brownish substance, are seen along the line of bedding.

Our remarks during the trials show that it kindles very readily and burns freely, raising the steam with great rapidity. It makes a remarkably clean fire, without any smoke, opening well on the bars, without caking. No clinkers were made; the ashes and cinders left were clean, and of a whitish colour.

——	December 10, 1st day.	December 11, 2nd day.	December 12, 3rd day.
Fire lighted	8h. 15m.	8h. 10m.	8h. 15m.
Steam up	9h.	9h. 15m.	9h. 20m.
Weight of Wood used	10 lbs.	10 lbs.	10 lbs.
Initial Temperature of Water in Boiler	200°	205°	209°
Temperature of Water in Tanks	42°	34°	33°
Barometer	..	..	..
Extremes of external Thermometer	..	..	..
Extremes of internal Thermometer	54°—66°	48°—62°	42°—54°
Dew-point	..	..	..
Area of Damper open	112 in.	112 in.	112 in.
Weight of Coals consumed	337·5 lbs.	309·5 lbs.	321 lbs.
Weight of Ashes left	8·5 lbs.	11·5 lbs.	16·5 lbs.
Per centage of combustible matter in Ashes	52·76	..	..
Weight of Cinder left	8·5 lbs.	12·5 lbs.	12·5 lbs.
Per centage of combustible matter in Cinder	89·74	..	..
Weight of Clinker in Cinder	None.	None.	None.
Average weight of Soot in Flues	1 lb.	1 lb.	1 lb.
Per centage of combustible matter in Soot	51·39	..	..
Weight of Water evaporated	2876 lbs.	2629 lbs.	2793 lbs.
Weight of Water evaporated from 212° by 1 lb. of Coals	10·07 lbs.	10·07 lbs.	10·307 lbs.
Weight of Coals per hour for 1 square foot of grate surface	8·43 lbs.	7·74 lbs.	8·01 lbs.
Duration of Experiment	8 hrs.	8 hrs.	8 hrs.
Specific gravity of Coal	1·326	..	..
Mean weight of cubic foot of Coal	53·22 lbs.	..	..
Economic weight or space occupied by 1 ton	42·09 c. f.	..	..
Cohesive power of Coal	56·2	..	..

Oldcastle Fiery Vein.

I, John Gibson, Agent for Messrs. Sims, Willyams, Neville, Druce, and Co., hereby certify, that the casks 1 and 2, addressed to John Wilson, Esq., contain a fair sample of the Oldcastle Fiery Vein hand-picked coals, which were mined specially for the service of the "Admiralty Coals Investigation."

This coal is obtained close to the sea-side, within half a mile of the town of Llanelly, and is worked at a depth from the surface of about 336 feet. The seam is 2 feet 6 inches in thickness, and is very regular throughout. The overlying stratum is strong rock, and the subjacent strong fire-clay. The dip of the seam is 4 to 5 inches in the yard, in a north and south direction; the strike of the bedding being east and west. The coal is of a bituminous character, and is worked nearly half large. The colliery is situate about one mile from the shipping port (Llanelly). The present market price is 6*s*. 6*d*. per ton as worked, and 9*s*. per ton if hand-picked large. England, Ireland, and France furnish the principal markets for the coal.

The sample of this coal has a dull lustrous appearance, similar to that of plumbago. It is a softish coal, with an imperfect fibrous structure, inclined at about 50° to the line of bedding, and contains very little pyrites or white matter. It breaks up readily into masses, having flat surfaces with irregular angles.

We remarked during the trial that, as soon as the fire burnt up and a high heat was obtained, a series of explosions, more or less loud, were heard throughout the day: being more frequent when fresh coal was thrown on, and gradually diminishing, both in intensity and frequency, as the coal was consumed. The fire was readily kindled and burnt well, making but little smoke or dirt. On the fire the coal swells up immediately, opens well, and cakes just enough to hold the small pieces together, without obstructing the passage of air through the bars.

——	December 21, 1st day.	December 22, 2nd day.	December 23, 3rd day.
Fire lighted	8h.	8h. 15m.	8h. 15m.
Steam up	10h. 45m.	8h. 45m.	8h. 40m.
Weight of Wood used	15 lbs.	10 lbs.	10 lbs.
Initial Temperature of Water in Boiler	70°	206°	210°
Temperature of Water in Tanks	47°	37°	37°
Barometer	29·15 in.	29·10 in.	28·76 in
Extremes of external Thermometer	..	..	33°—39°
Extremes of internal Thermometer	..	39°—52°	..
Dew-point	..	..	43°
Area of Damper open	112 in.	100 in.	112 in.
Weight of Coals consumed	365·5 lbs.	440 lbs.	438 lbs.
Weight of Ashes left	9 lbs.	9 lbs.	11·5 lbs.
Per centage of combustible matter in Ashes.	33·15	30·79	..
Weight of Cinder left	16 lbs.	18·5 lbs.	17·5 lbs.
Per centage of combustible matter in Cinder	74·72	60·99	..
Weight of Clinker in Cinder	None.	None.	None.
Average weight of Soot in Flues	..	..	..
Per centage of combustible matter in Soot	..	..	..

—	December 21, 1st day.	December 22, 2nd day.	December 23, 3rd day.
Weight of Water evaporated . . .	2259 lbs.	3327 lbs.	3451 lbs.
Weight of Water evaporated from 212° by 1 lb of Coal	8·65 lbs.	8·92 lbs.	9·72 lbs.
Weight of Coals per hour for 1 square foot of grate surface	10·44 lbs.	9·79 lbs.	9·72 lbs.
Duration of Experiment	7 hrs.	8 hrs.	9 hrs.
Specific gravity of Coal	1·289	..	..
Mean weight of cubic foot of Coal . .	50·916 lbs.	..	..
Economic weight or space occupied by 1 ton	43·19 c. f.	..	..
Cohesive power of Coal	57·7	..	..

Ward's Fiery Vein.

I, John Gibson, Agent for Messrs. Sims, Willyams, Neville, Druce, and Co., hereby certify, that the casks Nos. 3 and 4, addressed to John Wilson, Esq., contain a fair sample of Ward's Fiery Vein hand-picked coals, which were mined specially for the service of the "Admiralty Coals Investigation."

This colliery is situate about 1½ mile from the town of Llanelly, and 2½ miles from Laughor. The seam is 5 feet thick and very regular, and is worked at a depth of 426 feet from the surface. The strike is east and west, and rise north and south. The bottom stone is soft, the top a shaly blue stone, with a small quantity of iron-stone mixed. It has the character of a free-burning coal, and works very large. The colliery is about 2 miles from the port of Llanelly. The present current price is 6*s.* 3*d.* per ton as worked, and 9*s.* per ton for hand-picked. The principal markets are in England.

This is a soft coal, of a bright appearance, with a distinct fibrous structure, the direction of the lines of which is inclined to the planes of deposition, at an angle of about 45° across the planes of deposition; it appears to break very readily. Very little pyrites or white matter were seen in the sample of coal sent to us.

Our remarks during the trials are, that the fire was readily kindled, and that, during the whole period of the experiments, a hissing noise was distinctly heard in the fire, similar to that produced by throwing up wetted cinders or coals. The proportion of clinker was rather large, and of a reddish colour, containing much shale.

—	December 28, 1st day.	December 29, 2nd day.	December 30, 3rd day.
Fire lighted	8hrs.	8h. 10m.	8h. 10m.
Steam up	9h. 30m.	8h. 40m.	8h. 35m.
Weight of Wood used	10 lbs.	10 lbs.	10 lbs.
Initial Temperature of Water in Boiler .	110°	211°	212°
Temperature of Water in Tanks . .	33°	33°	33°
Barometer	30·55 in.	30·325 in.	30·645 in.
Extremes of external Thermometer . .	..	30°—32°	30°—38°
Extremes of internal Thermometer . .	38°—45°	44°—53°	45°—53°

——	December 28, 1st day.	December 29, 2nd day.	December 30, 3rd day.
Dew-point	..	..	..
Area of Damper open	112 in.	112 in.	112 in.
Weight of Coals consumed	484 lbs.	455 lbs.	414 lbs.
Weight of Ashes left	12 lbs.	9 lbs.	11 lbs.
Per centage of combustible matter in Ashes	23·6	15·01	15·51
Weight of Cinders left	19·5 lbs.	24 lbs.	22 lbs.
Per centage of combustible matter in Cinder	..	27·16	..
Weight of Clinker in Cinder	7·43 lbs.	11·5 lbs.	14· lbs.
Average weight of Soot in Flues	1·06 lbs.	1·06 lbs.	1·06 lbs.
Per centage of combustible matter in Soot	44·92	..	..
Weight of Water evaporated	3410 lbs.	3615 lbs.	3410 lbs.
Weight of Water evaporated from 212° by 1 lb. of Coal	9·17 lbs.	9·36 lbs.	9·69 lbs.
Weight of Coals per hour for 1 square foot of grate surface	12·1 lbs.	11·37 lbs.	9·2 lbs.
Duration of Experiment	8 hrs.	8 hrs.	9 hrs.
Specific gravity of Coal	1·344	..	..
Mean weight of cubic foot of Coal	57·433 lbs.	..	..
Economic weight or space occupied by 1 ton	39 c. f.	..	..
Cohesive power of Coal	46·5	..	..

Binea Coal.

This coal was forwarded to London at an early stage of the investigation, and before the plan of examination was arranged, consequently no certificate of their quality was furnished.

The coal is obtained on Binea Farm, near Laughor Bridge, in the county of Glamorgan, and is known as the Binea or Laughor Fiery Vein. It is worked by the ordinary means of picks, and without blasting, at a depth of about 240 feet from the surface. The average thickness is about 4 feet, and the vein runs very regular, lying between strata of strong blue stone. It is but very slightly inclined. It is called a free-burning coal, and appears to be used for locomotive and marine engines in the neighbouring ports and railways; large quantities are also sold in Ireland. The current price is 10*s*. per ton for large, and 7*s*. for the mixed and small. The colliery is about 3 miles from the port of Llanelly.

The sample of coal furnished had a bright appearance with some surfaces distinctly fibrous, others very irregular, apparently made up of rectangular masses, separated by numerous thin layers of Shaly matter. It is a soft coal, and contains but a very small quantity of pyrites and white matter. The surfaces of deposition are well marked, and average about $\frac{3}{4}$ of an inch apart. The lines of fibrous structure have an inclination of about 45° to the surface of deposition.

The only remarks made during the trials are, that both the cinders and the ashes left were of a reddish colour, and contained a large proportion of shaly matter, which, on being moved, broke down into a fine powder. No clinkers were found either on the bars or in the ash-pit.

——	December 31, 1st day.	January 1, 2nd day.	January 2, 3rd day.
Fire lighted	8h. 40m.	8h. 15m.	8h. 15m.
Steam up	9h. 10m.	8h. 35m.	8h. 40m.
Weight of Wood used	10 lbs.	10 lbs.	10 lbs.
Initial Temperature of Water in Boiler	212°	218°	218°
Temperature of Water in Tanks	33°	33°	36°
Barometer	30·858 in.	30·33 in.	29·972 in.
Extremes of external Thermometer	22°—33°	28°—32°	32°—36°
Extremes of internal Thermometer	46°—51°	48°—51°	44°—55°
Dew-point	36°	42°	36°
Area of Damper open	56 in.	56 in.	56 in.
Weight of Coals consumed	384 lbs.	372 lbs.	366 lbs.
Weight of Ashes left	12·5 lbs.	11 lbs.	14·5 lbs.
Per centage of combustible matter in Ashes	16·42	30·18	47·8
Weight of Cinder left	20 lbs.	12 lbs.	18 lbs.
Per centage of combustible matter in Cinder	36·41	47·87	66·85
Weight of Clinker in Cinder	None.	None.	None.
Average weight of Soot in Flues	1·45 lbs.	1·45 lbs.	1·45 lbs.
Per centage of combustible matter in Soot	39·74	..	..
Weight of Water evaporated	3163 lbs.	3163 lbs.	3204 lbs.
Weight of Water evaporated from 21° by 1 lb. of Coals	9·7 lbs.	9·93 lbs.	10·208 lbs.
Weight of Coals per hour for 1 square foot of grate surface	9·6 lbs.	9·3 lbs.	9·15 lbs.
Duration of Experiment	7 hrs.	8 hrs.	8 hrs.
Specific gravity of Coal	1·304	..	..
Mean weight of cubic foot of Coal	57·08 lbs.	..	..
Economic weight or space occupied by 1 ton	39·24 c. f.	..	..
Cohesive power of Coal	51·2	..	..

Llangennech Coal.

The sample of these coals was furnished to the investigation through the hands of Messrs. Neville, of Llanelly, and has been submitted to precisely the same treatment as those sent, either by those gentlemen or by other proprietors. My application to the proprietors of this colliery for the usual particulars has not, however, been attended to, and I therefore am unable to include them in this report.—J. W.

These coals have rather a dull appearance, are soft, and have a structure almost wholly fibrous, and contain minute quantities of iron pyrites, and but little white matter. Their fracture is very irregular, and the natural softness of the coals renders them easily reduced to powder (probably this is the cause of their dull appearance). They appear to have a great disposition to break up into oblique angled masses: the fracture across the fibrous structure resembles that of antimony, only the grain is much coarser. Small thin plates of shaly matter occasionally occur, but of a very small size in general.

The remarks made during the trials are, that the ashes, cinders, and clinkers were of a reddish colour, containing much white and shaly matter; the clinkers were very thin, and, when removed from the fire bars and thrown on the fire, they were again burnt through with some difficulty. On treating the white matter of the clinker with hydrochloric acid, a strong odour of sulph. hydrogen was given out. They burnt very readily in a common house grate, leaving a light-coloured ash.

——	January 7, 1st day.	January 8, 2nd day.	January 9, 3rd day.
Fire lighted	8 hrs.	8h. 15m.	8 hrs.
Steam up	8h. 35m.	8h. 35m.	8h. 20m.
Weight of Wood used	10 lbs.	10 lbs.	10 lbs.
Initial Temperature of Water in Boiler	178°	214°	215°
Temperature of Water in Tanks	44°	44°	42°
Barometer	30·15 in.	30·175 in.	30·398 in.
Extremes of external Thermometer	41°—45°	41°—48°	35°—39°
Extremes of internal Thermometer	49°—55°	52°—55°	49°—55°
Dew-point	53°	46°	48°
Area of Damper open	49 in.	49 in.	49 in.
Weight of Coals consumed	304 lbs.	365 lbs.	342 lbs.
Weight of Ashes left	7 lbs.	12 lbs.	17 lbs.
Per centage of combustible matter in Ashes	42·27	15·75	41·89
Weight of Cinder left	21 lbs.	27 lbs.	26 lbs.
Per centage of combustible matter in Cinder	83·79	56·83	39·64
Weight of Clinker in Cinder	9 lbs.	12 lbs.	10 lbs.
Average weight of Soot in Flues	75 lbs.	75 lbs.	75 lbs.
Per centage of combustible matter in Soot	38·67	..	..
Weight of Water evaporated	2465 lbs.	2629 lbs.	2588 lbs.
Weight of Water evaporated from 212° by 1 lb of Coal	9·91 lbs.	8·37 lbs.	8·32 lbs.
Weight of Coals per hour for 1 square foot of grate surface	7·6 lbs.	9·12 lbs.	8·55 lbs.
Duration of Experiment	8 hrs.	8 hrs.	8 hrs.
Specific gravity of Coal	1·312	..	..
Mean weight of cubic foot of Coal	56·93 lbs.	..	..
Economic weight or space occupied by 1 ton	39·34 c. f.	..	..
Cohesive power of Coal	53·5	..	..

Mynydd Newydd.

I hereby certify that the two casks, marked M N, No. 3, contain a fair sample of the Mynydd Newydd coals, which were mined specially for the service of the "Admiralty Coals Investigaton."—J. E. Morrice, *Agent for Swansea Coal Company.*

This coal is generally known by the name of the Penyfilia or 5-feet vein, and is mined near Cadley, in the parish of Llangavelach. The vein varies from 5 feet to 7 feet in thickness, and is worked at a depth of 306 feet from the surface. The subjacent stratum is composed of soft cliff roof for 8 fathoms, with sandstone over. The inclination of the vein is 3 inches in the yard, and the direction 60° south-west. The coal is of a very bituminous character, and is used for household purposes generally, and also at the Copper Smelting Works, at Swansea, where the current price is about 5*s.* 6*d.* for the small, and 7*s.* 6*d.* per ton for the screened and shipping. It is much esteemed for house purposes, being considered very free from sulphur.

The sample of coal sent to us for trial was of a small size, having been badly packed, and moved about from several places. It appeared, however, to be a moderately hard coal, of a compact structure, with an irregular fracture. The mass seemed to be made up of slightly rounded surfaces, with a fine fibrous structure, the cross section of which presented a finely mottled appearance. The brown fibrous matter, so frequently met with, was found in small quantities, but no pyrites or white matter were seen.

The remarks at the trials were, that, owing to the smallness of the coals, they caked immediately on the fire, causing much smoke, and delaying the generation of steam. On moving the fire, much unburnt coal ran through the fire bars, and fell into the ash-pit. The proportions of clinkers, cinders, and ashes were very considerable.

——	January 11, 1st day.	January 12, 2nd day.	January 13, 3rd day.
Fire lighted	8h. 35m.	8h. 10m.	8h. 15m.
Steam up	9h. 20m.	8h. 35m.	8h. 35m.
Weight of Wood used	10 lbs.	10 lbs.	10 lbs.
Initial Temperature of Water in Boiler	188°	218°	218°
Temperature of Water in Tanks	34°	34°	37°
Barometer	30·25 in.	30·075 in.	29·924 in.
Extremes of external Thermometer	..	31°—36°	32°—35°
Extremes of internal Thermometer	47°—53°	45°—52°	48°—56°
Dew-point	37°·5	44°	48°
Area of Damper open	126 in.	126 in.	126 in.
Weight of Coals consumed	413 lbs.	377 lbs.	395 lbs.
Weight of Ashes left	14 lbs.	11 lbs.	12 lbs.
Per centage of combustible matter in Ashes	20·43	50·43	48·96
Weight of Cinder left	18 lbs.	21 lbs.	19 lbs.
Per centage of combustible matter in Cinder	35·46	58·38	42·34
Weight of Clinker in Cinder	9·14 lbs.	11·13 lbs.	11 lbs.
Average weight of Soot in Flues	1 lb.	1 lb.	1 lb.
Per centage of combustible matter in Soot	41·31	..	..
Weight of Water evaporated	3368 lbs.	3040 lbs.	3140 lbs.
Weight of Water evaporated from 212° by 1 lb. of Coal	9·83 lbs.	9·41 lbs.	9·34 lbs.
Weight of Coals per hour for 1 square foot of grate surface	10·32 lbs.	9·42 lbs.	9·67 lbs.
Duration of Experiment	8 hrs.	8 hrs.	8 hrs.
Specific gravity of Coal	1·31	..	..
Mean weight of cubic foot of Coal	56·33 lbs.	..	..
Economic weight or space occupied by 1 ton	39·76 c. f.	..	..
Cohesive power of Coal	53·7	..	..

Three-quarter Rock Vein.

I hereby certify that the three casks, marked T Q R V S, contain a fair sample of the Three-quarter Rock Vein steam coals, which were mined especially for the service of the "Admiralty Coals Investigation."—Thomas Black.

This is known as the Three-quarter Vein, and is situate near to the Varteg Iron Company's works. It is obtained at a depth of from 210 to 240 feet from the surface ; and the vein runs from 4 to 5 feet in thickness, and is worked in stalls and pillars. The subjacent and overlying strata are clunch coal, iron-stone, balt, clay, rock and iron-stone. The dip is 3½ inches in the yard, in a westerly direction. The character of the coal is free burning, with a pure white ash, containing little sulphur, and working large. The colliery is 15¼ miles from the shipping port (Newport) ; the principal markets are the East and West Indies, Brazils, Africa, and the Mediterranean ports, and the present price current is 9*s.* 6*d.* per ton.

This coal has a dull appearance, and is of a firm compact character, split-

ting readily along the bedding, which is often defined by layers of a soft brown matter. It breaks up very irregularly, the pieces are small, of a cubical shape, with flat surfaces. The joints appear to be at right angles with the plane of deposition, and contain large quantities of pyrites, and a white substance, of a hard semi-crystalline appearance, which, on being examined, proved to consist chiefly of silica, with lime, magnesia, and traces of sulphur. The mass of the coal is composed of thin plates of coal, alternating with plates of shale. The sample, when received by us, seemed to have been exposed to rain, as the coal was in a very wet state.

Our remarks during the trials were, that the fire kindled freely, but required a strong draught, making much smoke at first, of a dense black nature, which, as the fire burnt up in the course of the day, assumed a reddish-brown tint. It caked quickly on the fire, and coked easily on the dead plate; much sooty matter was deposited on the top of the dead plate, and also in thin leaves adhering to the top of the fire-grate. The cinders and ashes, when thrown up, burnt well. The proportions of residua, ash, cinders, clinkers, and soot, were rather large. In a common fire-grate it burnt well, leaving a light-coloured ash.

——	January 14, 1st day.	January 15, 2nd day.	January 16, 3rd day.
Fire lighted	8h. 35m.	8h. 10m.	8h.
Steam up	9h.	8h. 35m.	8h. 20m.
Weight of Wood used	10 lbs.	10 lbs.	10 lbs.
Initial Temperature of Water in Boiler	217°	219°	219°
Temperature of Water in Tanks	36°	36°	36°
Barometer	30·064 in.	30·11 in.	30·096 in.
Extremes of external Thermometer	29°—39°	29°—38°	29°—36°
Extremes of internal Thermometer	48°—45°	45°—54°	48°—52°
Dew-point	45°·5	45°	40°
Area of Damper open	120 in.	132 in.	72 in.
Weight of Coals consumed	444 lbs.	470 lbs.	408 lbs.
Weight of Ashes left	9 lbs.	10 lbs.	12 lbs.
Per centage of combustible matter in Ashes	36·71	..	40·82
Weight of Cinder left	21 lbs.	18 lbs.	22 lbs.
Per centage of combustible matter in Cinder	50·09	..	80·96
Weight of Clinker in Cinder	10·12 lbs.	8 lbs.	7·14 lbs.
Average weight of Soot in Flues	1·5 lbs.	1·5 lbs.	1·5 lbs.
Per centage of combustible matter in Soot	43·77	..	..
Weight of Water evaporated	3394 lbs.	3533 lbs.	3081 lbs.
Weight of Water evaporated from 212° by 1 lb. of Coal	8·91 lbs.	8·84 lbs.	8·79 lbs.
Weight of Coals per hour for 1 square foot of grate service	11·1 lbs.	11·75 lbs.	10·2 lbs.
Duration of Experiment	8 hrs.	8 hrs.	8 hrs.
Specific gravity of Coal	1·34	..	..
Mean weight of cubic foot of Coal	56·38 lbs.	..	..
Economic weight or space occupied by 1 ton	39·72 c. f.	..	..
Cohesive power of Coal	52·7	..	..

Graigola Coal.

No certificate; the coal having been sent up at the commencement of the investigation.—J. W.

This coal is known as the Graigola coal, and is obtained at Graigola, on the eastern side of the river Tawe, about 6 miles from Swansea, in the hamlet of Ynisymond, parish of Cadoxton-juxta-Neath. It is worked by short work —by holding in the under coal, and in the face of the slips; the object being to get as great a proportion as possible of large coal. The seams are worked by level, and are about 5 feet 9 inches in thickness, running very regular; both the under and over lying strata being a hard and solid sandstone. The inclination is about 3 inches to the yard, or 1 in 12, with a north rise. The coal is described as a free-burning coal, with little smoke or sulphur. The current price is 10*s.* per ton for large hand-picked; the small is 3*s.* 6*d.* per ton. The principal markets are London, Mediterranean, Africa, Jamaica, and the various stations both at home and abroad. The coal appears to be used for making coke in open pits, and, when mixed up with a proportion of bituminous coal, is well adapted for smelting, &c.

The coal is of a soft character, tolerably bright appearance, and apparently fibrous structure, the lines being often inclined so as to form irregular cone-shaped masses, the general inclination being about 45° to the plane of deposition. Irregular patches of a soft brown substance are seen generally along the line of the bedding, with thin layers of a shaly nature. In the sample sent, no pyrites were observed, and but a very small quantity of whitish matter in the jointings.

Our remarks during the trials were, that the fire kindled easily and burnt well, though we had some trouble at first, owing to the small size of the coal. It had been very badly packed, and, having been removed several times, its natural softness had caused it to separate into very small pieces. On the fire, the coal opens out well, but is apt to split into small pieces, which fall on the bars and stop up the current of air, and, if moved, fall through to the ash-pit. It seemed best to use pieces of a moderate size, and to leave them on the fire without much stoking. The ashes, cinder, and clinker were in considerable quantity, and of a very small size, and reddish colour: the clinker being mixed up with scoria and dirt of a friable description. In a common grate it burnt well, leaving but very little ash.

—	January 18, 1st day.	January 19, 2nd day.	January 20, 3rd day.
Fire lighted	8h. 50m.	8h. 15m.	8h. 10m.
Steam up	9h. 20m.	8h. 40m.	8h. 30m.
Weight of Wood used	10 lbs.	10 lbs.	10 lbs.
Initial Temperature of Water in boiler	190°	218°	218°
Temperature of Water in Tanks	34°	36°	36°
Barometer	30·155 in.	30·215 in.	30·1 in.
Extremes of external Thermometer	..	32°—39°	30°—36°
Extremes of internal Thermometer	45°—50°	45°—52°	45°—52°
Dew-point	38°·5	41°	42°

—	January 18, 1st day.	January 19, 2nd day.	January 20, 3rd day.
Area of Damper open	49 in.	49 in.	49 in.
Weight of Coals consumed	416 lbs.	364 lbs.	354 lbs.
Weight of Ashes left	10 lbs.	18 lbs.	21 lbs.
Per centage of combustible matter in Ashes	32·99	37·96	51·64
Weight of Cinder left	17 lbs.	17 lbs.	17 lbs.
Per centage of combustible matter in Cinder	60·57	38·66	39·74
Weight of Clinker in Cinder	6·5 lbs.	6 lbs.	3 lbs.
Average weight of Soot in Flues	1·25 lbs.	1·25 lbs.	1·25 lbs.
Per centage of combustible matter in Soot	46·24 lbs.	..	..
Weight of Water evaporated	3204 lbs.	2958 lbs.	2835 lbs.
Weight of Water evaporated from 212° by 1 lb. of Coal	9·27 lbs.	9·47 lbs.	9·3 lbs.
Weight of Coal per hour for 1 square foot of grate surface	10·4 lbs.	9·1 lbs.	8·85 lbs.
Duration of Experiment	8 hrs.	8 hrs.	8 hrs.
Specific gravity of Coal	1·3	..	..
Mean weight of cubic foot of Coal	60·16 lbs.	..	..
Economic weight or space occupied by 1 ton.	37·23 c. f.	..	..
Cohesive power of Coal	49·3	..	..

Park End Coals, Lydney.

I hereby certify that the 10 casks and boxes, marked Nos. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, contain a fair sample of the best Park End coals, which were mined specially for the service of the "Admiralty Coals Investigation."—Thomas Nicholson, *occupying Tenant of the Park End Colliery.*

This coal is known as the Park End High Delf or Lowry Vein, and is obtained at Park End, near Lydney, in the Forest of Dean. The vein is generally regular, and about three feet thick, and is worked long work, as in the thin veins of the Staffordshire coal-field. The overlying and subjacent strata are of the usual kind of shale. The dip varies from 6 inches to 2 feet in the yard, or from 1 in 6 to 2 in 3. The coal *is described* to be "of a free-burning character, of great strength and durability." The distance from the shipping port, Lydney, is five miles. The current price in summer is 10*s.* per ton, in winter 11*s.*, free on board, and the principal markets are in Ireland, Cornwall, Cheltenham, and the manufacturing districts of Gloucestershire and Bridgewater.

The coal forwarded for investigation had a very hard and compact structure, with a clean and bright fracture, and contained iron pyrites in very large quantities in every joint, even when broken down into the smallest sized pieces. It also contained to a considerable extent the white substance found in many of the other samples of coals sent to us. The bedding was very regular and well defined, along the planes of which the coal readily separated. The jointings appeared to be at right angles to the plane of deposition, where we usually found thin layers of a brown, soft, and silky substance, similar to that seen in other samples.

We remarked during the trials that the coal kindled easily, but that it

made a very dirty, smoky fire, which, at the ordinary working draught, caused immense volumes of dense smoke to appear at the chimney top. When the draught was increased the fire became clearer, but then the rush of smoke swept the loose soot from the flues and chimney, and carried it out in large flakes from the chimney top. If the draught was lessened, the fire would hardly burn, and, on opening the doors, the whole place was instantly filled with the loose ashes and smoke forced out from the fire. The cinders, ashes, and clinker were of a light weight and clean: the clinker contained much scoria, some of it quite vitrified. A palpable smell of sulph. hydrogen was perceived when the opening of the fire-doors caused the smoke to be driven into the boiler-house.

——	January 21, 1st day.	January 22, 2nd day.	January 23, 3rd day.
Fire lighted	8h. 30m.	8h. 15m.	7h. 55m.
Steam up	8h. 50m.	8h. 30m.	8h. 15m.
Weight of Wood used	10 lbs.	10 lbs.	10 lbs.
Initial Temperature of Water in Boiler	217°	219°	219°
Temperature of Water in Tanks	34°	38°	39°
Barometer	29·96 in.	29·824 in.	29·674 in.
Extremes of external Thermometer	32°—36°	35°—43°	32°—42°
Extremes of internal Thermometer	44°—52°	47°—55°	45°—57°
Dew-point	41°	45°	47°
Area of Damper open	144 in.	112 in.	112 in.
Weight of Coals consumed	478 lbs.	441 lbs.	451 lbs.
Weight of Ashes left	5 lbs.	4 lbs.	7 lbs.
Per centage of combustible matter in Ashes	31·14	37·52	31·82
Weight of Cinder left	9 lbs.	12 lbs.	18 lbs.
Per centage of combustible matter in Cinder	55·19	19·23	49·26
Weight of Clinker in Cinder	3·6 lbs.	4·6 lbs.	7·8 lbs.
Average Weight of Soot in Flues	1·25 lbs.	1·25 lbs.	1·25 lbs.
Per centage of combustible matter in Soot	35·15	..	..
Weight of Water evaporated	3673 lbs.	3286 lbs.	3081 lbs.
Weight of Water evaporated from 212° by 1 lb. of coal	8·99 lbs.	8·66 lbs.	7·93 lbs.
Weight of Coals per hour for 1 square foot of grate surface	11·95 lbs.	11·02 lbs.	11·27 lbs.
Duration of Experiment	8 hrs.	8 hrs.	8 hrs.
Specific gravity of Coal	1·283	..	..
Mean weight of cubic foot of Coal	54·44 lbs.	..	..
Economic weight or space occupied by 1 ton	41·14 c. f.	..	..
Cohesive power of Coal	55	..	..

Pentrepoth Coal.

I hereby certify that the three casks, marked No. 2, contain a fair sample of the Pentrepoth coals, which were mined specially for the "Admiralty Coals Investigation."—J. E. Morrice, *Agent for the Swansea Coal Company.*

This coal is generally called the 4-feet or Church Pit Vein, and is situate near Morriston, in the parish of Llangavelach. The vein runs about 4 feet thick, but is very irregular, and is worked at a depth from the surface of about 66 feet. The underlying stratum is soft cliff, with hard cliff over the beds. The dip is 6 inches in the yard, or 1 in 6, with a northerly direction.

The coal is called free burning, and the current price at the copper works in Swansea, where alone it appears to be used, is about 44*s.* per 11 tons, or 4*s.* per ton. The distance of the colliery from the port is 3½ miles.

The sample of this coal sent appeared to have been badly packed, as the coal, being soft, was broken into very small pieces. It appeared to be of a bright fibrous structure, but not so distinctly so as many other sorts sent up to us for investigation; the peculiar cone-shaped form being, however, well defined. The coal was of a very soft character, containing thin laminæ of a very bright coal, somewhat firmer in structure. In the bedding, a dark-brown soft substance was found, but otherwise the body of the coal was very clean, and free both from pyrites and the white substance so frequently met with.

Our remarks during the trials are, that the Pentrepoth coal burnt with great difficulty, unless a deep fire is kept up, and the charge continually thrown on the top of the fire in very small quantities at a time. Little or no smoke was given off, and a very high local temperature was produced by the combustion of the large quantity of coal on the fire-bars. The same scintillations were seen throughout the trials as with the Pentrefelin coal, and also the same hissing noise while burning. More wood was necessary to light up with than usual. The ashes, cinders, and soot were also in large proportions, though much of the latter was blown away while raking out the flues.

——	January 25, 1st day.	January 26, 2nd day.	January 27, 3rd day.
Fire lighted	9 hrs.	8h. 15m.	8h. 15m.
Steam up	9h. 50m.	9 hrs.	8h. 45m.
Weight of Wood used	15 lbs.	15 lbs.	15 lbs.
Initial Temperature of Water in Boilers	185°	194°	216°
Temperature of Water in Tanks	43°	43°	45°
Barometer	29·39 in.	29·494 in.	29·47 in.
Extremes of external Thermometer	..	39°—43°	43°—47°
Extremes of internal Thermometer	50°—53°	51°—58°	52°—59°
Dew-point	43°	44°	47°
Area of Damper open	126 in.	56 in.	56 in.
Weight of Coals consumed	357 lbs.	375 lbs.	319 lbs.
Weight of Ashes left	13 lbs.	8 lbs.	11 lbs.
Per centage of combustible matter in Ashes	37·75	38·97	38·78
Weight of Cinder left	27 lbs.	22 lbs.	25 lbs.
Per centage of combustible matter in Cinder	49·94	52·28	39·67
Weight of Clinker in Cinder	14·25 lbs.	10·5 lbs.	12·9 lbs.
Average weight of Soot in Flues	1·125 lbs.	1·125 lbs.	1·125 lbs.
Per centage of combustible matter in Soot	48·62	..	..
Weight of Water evaporated	2463 lbs.	2758 lbs.	2538 lbs.
Weight of Water evaporated from 212° by 1 lb of Coal	8·3 lbs.	8·72 lbs.	9·14 lbs.
Weight of Coals per hour for 1 square foot of grate surface	8·92 lbs.	9·37 lbs.	7·27 lbs.
Duration of Experiment	8 hrs.	8 hrs.	8 hrs.
Specific gravity of Coal	1·31	..	..
Mean weight of cubic foot of Coal	57·72 lbs.	..	..
Economic weight or space occupied by 1 ton	38·8 c. f.	..	..
Cohesive power of Coal	46·5	..	..

Cwm Frood Rock Vein.

I hereby certify that the three casks, marked C.R.V.S., contain a fair sample of the Cwm Frood Rock Vein steam coals, which were mined specially for the service of the "Admiralty Coals Investigation."—Thomas Black.

This coal is obtained at Cwm Frood, near to the works of the Varteg Iron Company. The vein runs from 5 to 6 feet in thickness, is very regular, and is worked in stalls and pillars, at a depth of 270 to 300 feet from the surface. The strata in which it lies are clunch coal, iron-stone, clay-coal, fire-clay, and rock; the dip being about 3½ inches in the yard, and in a westerly direction. The colliery is about 15 miles from Newport, the port at which it is shipped. The principal markets are the Brazils, East and West Indies, Africa, and the Government contracts, in which it was admitted about four years ago. The price current is 9*s.* 6*d.* per ton.

The general appearance of this coal is dull, with iridescent plates of iron pyrites and opaque white plates on its surface. In the planes of deposition or bedding a dull brown matter of a soft pulverulent character, containing small white particles, was seen in some quantity. The coal was of a much harder structure than most others that we have had from the South Wales basin, and had a very irregular fracture, though with a great tendency to separate into small rectangular masses. It appeared to be made up of layers of shaly matter, alternating with thin layers of bright coal, and split up easily, though irregularly, along the planes of deposition. Large quantities both of pyrites and white substance were found disseminated through the entire mass, showing themselves chiefly in the jointings.

Our remarks during the experiments were, only, that the fire appeared dirty and smoky, and that at times large quantities of smoke were seen from the chimney, and that a large proportion of soot was obtained from the flues, of a very dark colour and very light weight.

——	January 28, 1st day.	January 29, 2nd day.	January 30, 3rd day.
Fire lighted	8h. 40m.	8h. 15m.	8h. 15m.
Steam up	9h. 10m.	8h. 35m.	8h. 40m.
Weight of Wood used	10 lbs.	10 lbs.	10 lbs.
Initial Temperature of Water in Boiler	214°	217°	216°
Temperature of Water in Tanks	46°	46°	39°
Barometer	29·152 in.	29·414 in.	29·54 in.
Extremes of external Thermometer	43°—47°	35°—43°	29°—40°
Extremes of internal Thermometer	52°—58°	47°—57°	46°—54°
Dew-point	45·5°	44·5°	45·5°
Area of Damper open	..	..	..
Weight of Coals consumed	333 lbs.	340 lbs.	374 lbs.
Weight of Ashes left	7 lbs.	7 lbs.	9 lbs.
Per centage of combustible matter in Ashes	46·27	38·9	27·45
Weight of Cinder left	18 lbs.	16 lbs.	21 lbs.
Per centage of combustible matter in Cinder	17·72	32·89	35·64
Weight of Clinker in Cinder	4·8 lbs.	5 lbs.	8· lbs.
Average weight of Soot in Flues	1·3 lbs.	1·3 lbs.	1·3 lbs.
Per centage of combustible matter in Soot	52·41	..	..

—	January 28, 1st day.	January 29, 2nd day.	January 30, 3rd day.
Weight of Water evaporated	2479 lbs.	2571 lbs.	2812 lbs.
Weight of Water evaporated from 212° by 1lb of Coal	8·63 lbs.	8·73 lbs.	8·75 lbs.
Weight of Coals per hour for 1 square foot of grate surface	8·32 lbs.	8·5 lbs.	9·35 lbs.
Duration of Experiment	8 hrs.	8 hrs.	8 hrs.
Specific gravity of Coal	1·255	..	..
Mean weight of cubic foot of Coal . . .	55·27 lbs.	..	..
Economic weight or space occupied by 1 ton	40·52 c. f.	..	..
Cohesive power of Coal	72·5	..	..

Anthracite.

This coal was forwarded to London at the commencement of the investigation, and before any distinct plans of operation were decided upon, consequently no certificate was furnished with it.—J. W.

This coal is obtained in the parish of Llanguicke, in the county of Glamorgan, and is known by the name of the Brass Vein of the Cwmllynfell Colliery. It is worked at a depth of 318 feet from the surface, the galleries extending for some distance to the crop of the vein, the stalls most to the rise being about 226 feet from the surface. It is called a 4-feet vein, and is about 3 feet 10 inches in thickness, and very regular. The dip in general is from 5 to 6 inches in the yard, and in a southerly direction; however, there are several pans and saddles, which at intervals change the inclination and direction. There is also one extensive fault running nearly north and south. The overlying and subjacent strata appear to be argillaceous shales, interspersed with other veins of coal, and several veins of iron-stone and fire-clay.

The character of the coal is anthracite, and it is chiefly used in the hop and malt districts of England; the small coal is used also for lime-burning. The colliery is about 16 miles from the port of Swansea, where the current price is 12*s*. to 13*s*. per ton for the large, and 5*s*. to 6*s*. per ton for the small. There appear to be several other veins of anthracite coal in the neighbourhood. This vein is liked best for the malt and hop kilns, though a 6-feet vein, called the Big Vein, and a 3-feet vein, called the Little Vein, are most preferred for iron-smelting. This "Brass Vein" takes its name from a vein of pyrites, ¼ to 3 inches thick, which runs through it; the coal in its immediate vicinity is considered by the colliers to be brighter, harder, and purer than any other portion of the vein.

This anthracite coal has a bright appearance, with a shining irregular fracture; the bedding is tolerably well defined, with layers of a soft brown substance at a considerable distance from each other. It breaks with a semi-vitreous fracture into irregular very brittle masses. Although the structure of the coal is hard, still, from its brittle character, it is without difficulty broken up into small pieces.

We remarked on the first day's trial, that it was with great difficulty that we got the coal sufficiently kindled to get the steam up, nearly three hours

intervening between the time of lighting up and that of getting up the steam; we therefore found it necessary on the following day to increase our quantity of wood, and also to use a given weight of another description of coal, in order to obtain that temperature which the anthracite appears to require before it will enter into combustion. When once that takes place, the heat given off is intense, and the fire is very readily sustained. It is very advisable to supply the coal in small pieces, about the size of an egg, and gradually to raise their temperature by throwing them on the dead plate first, and thence on to the fire; by such means we materially prevent that splitting into small pieces which the sudden application of a great heat is sure to occasion in all coal of the same structural composition as the anthracites. The quantities of cinders and ashes were larger than with many other coals; they were of very small size, and both contained, when broken up and examined, varying proportions of pure and unaltered coal surrounded by the burnt mass. The clinker was very small in quantity, and in very small and very hard pieces. The fire kept burning for an unusually long time after the firing had ceased, as seen by the working sheet for the first day's trial: we left off charging at 5h. 45m., the steam, however, was blowing off up to 10 p. m., and the fire remained in up to 10h. 45m.

——	February 1, 1st day.	February 2, 2nd day.	February 3, 3rd day.
Fire lighted	8h. 40m.	8h. 45m.	9h.
Steam up	11h. 15m.	9h. 45m.	10h. 40m.
Weight of Wood used	10 lbs.	15 lbs.	10 lbs.
Initial Temperature of Water in Boiler	180°	214°	189°
Temperature of Water in Tanks	37°	40°	35°
Barometer	29·57 in.	29·87 in.	29·65 in.
Extremes of external Thermometer	..	31°—35°	..
Extremes of internal Thermometer	45°—50°	45°—51°	43°—50°
Dew-point	40°·5	40°·5	38°
Area of Damper open	56 in.	56 in.	56 in.
Weight of Coals consumed	363 lbs.	336 lbs.	340 lbs.
Weight of Ashes left	8 lbs.	19 lbs.	10 lbs.
Per centage of combustible matter in Ashes	22·65	28·57	49·14
Weight of Cinder left	18 lbs.	23 lbs.	18 lbs.
Per centage of combustible matter in Cinder	44·66	30·07	37·13
Weight of Clinker in Cinder	None.	..	..
Average weight of Soot in Flues	1 lb.	1 lb.	1 lb.
Per centage of combustible matter in Soot	42·82	..	..
Weight of Water evaporated	2734 lbs.	3024 lbs.	2857 lbs.
Weight of Water evaporated from 212° by 1lb. of Coal	9·19	9·74	9·46
Weight of Coals per hour for 1 square foot of grate surface	9·07 lbs.	8·4 lbs.	8·49 lbs.
Duration of Experiment	8 hrs.	8 hrs.	8 hrs.
Specific gravity of Coal	1·375	..	..
Mean weight of cubic foot of Coal	58·25	..	..
Economic weight or space occupied by 1 ton	38·45 c. f.	..	..
Cohesive power of Coal	68·5	..	..

Cwm Nanty-Gros.

No certificate has been received respecting these coals.—J. W.

The sample of coal sent up for the trials was of a softish character, the bedding well-defined, with laminæ of shaly matter, varying in thickness, and of great hardness, with irregular plates of a brownish-black substance of a soft and silky appearance. The general structure of the coal was very irregular, and large quantities of pyrites of a light colour were perceptible throughout the mass, together with a smaller quantity of a white substance, like that met with in several of the other coals, but not in such large and flat plates.

The coal broke up easily into small pieces; it kindled readily, and seemed to coke well upon the dead plate, making rather a smoky fire, which, however, by careful stoking and regulation of draught, did not appear at the chimney top as smoke. No other remarks were made during the experiments.

——	February 4, 1st day.	February 5, 2nd day.	February 6, 3rd day.
Fire lighted	8h. 15m.	8h. 15m.	8h. 15m.
Steam up	8h. 45m.	8h. 40m.	8h. 40m.
Weight of Wood used	10 lbs.	10 lbs.	10 lbs.
Initial Temperature of Water in Boiler	183°	215°	216°
Temperature of Water in Tanks	36°	37°	43°
Barometer	30·20 in.	30·16 in.	29·68 in.
Extremes of external Thermometer	32°—35°	29°—40°	38°—43°
Extremes of internal Thermometer	43°—51°	45°—53°	49°—57°
Dew-point	42°·5	43°	48°·5
Area of Damper open	84 in.	12·6 in.	84· in.
Weight of Coals consumed	414 lbs.	369 lbs.	370 lbs.
Weight of Ashes left	7 lbs.	6 lbs.	7 lbs.
Per centage of combustible matter in Ashes	18	11·71	21·78
Weight of Cinder left	13 lbs.	12 lbs.	13 lbs.
Per centage of combustible matter in Cinder	30·57	36·25	31·09
Weight of Clinker in Cinder	4·11 lbs.	4·3 lbs.	3·8 lbs.
Average weight of Soot in Flues	1·56 lbs.	1·56 lbs.	1·56 lbs.
Per centage of combustible matter in Soot	39·45	..	..
Weight of Water evaporated	2853 lbs.	2734 lbs.	2605 lbs.
Weight of Water evaporated from 212° by 1 lb. of Coal	8·38 lbs.	8·65 lbs.	8·23 lbs.
Weight of Coals per hour for 1 square foot of grate surface	10·34 lbs.	9·24 lbs.	9·24 lbs.
Duration of Experiment	8 hrs.	8 hrs.	8 hrs.
Specific gravity of Coal	1·28	..	..
Mean weight of cubic foot of Coal	56 lbs.	..	..
Economic weight or space occupied by 1 ton	40 c. f.	..	..
Cohesive power of Coal	55·7	..	..

Wylam's Patent Fuel.

This patent fuel was purchased of the company from the stock with which the market was at the time supplied, and therefore no certificate was required.—J. W.

It is made and sold in blocks, weighing about 13 lbs. each, of an oblong rectangular shape, being 12″ × 6″ × 5″. The charge-box, used for taking

the economic weight of a cubic foot of coal, not being adapted for these blocks, we took 24 of them, and built them up so as to form a parallelopiped $24'' \times 20'' \times 18''$, and then found it to weigh 329 lbs., which gives $\frac{329}{5} = 65\cdot8$ lbs. per cubic foot. The blocks, when broken, show an irregular fracture, and appear to be composed of small pieces of coal forcibly compressed and cemented together by some bituminous substance, giving off a strong odour of mineral pitch when heat is applied to them.

Our remarks during the trials show that the fire was readily kindled and steam quickly got up, but much smoke always appeared in the fire, though with a slow draught, but little was seen from the chimney. The fuel swells up on the fire, and separates from the mass in large flakes, which are readily burnt, leaving a fresh surface for the action of the fire.

The proportions of cinders, ashes, and clinkers were considerable; the ashes having a reddish colour, containing much very small clinkers. The soot also was in large quantities, and no doubt, with a quicker draught, would have produced much smoke.

——	February 11, 1st day.	February 12, 2nd day.	February 13, 3rd day.
Fire lighted	8 hrs.	8h. 10m.	8h. 10m.
Steam up	9 hrs.	8h. 30m.	8h. 35m.
Weight of Wood used	10 lbs.	10 lbs.	10 lbs.
Initial Temperature of Water in Boiler	160°	214°	214°
Temperature of Water in Tanks	33°	34°	34°
Barometer	29·77 in.	29·92 in.	30·07 in.
Extremes of external Thermometer	20°—30°	13°—°31	21°—30°
Extremes of internal Thermometer	40°—47°	39°—47°	39°—41°
Dew-point	39° ·5	37°	44°
Area of Damper open	140 in.	84 in.	84 in.
Weight of Coals consumed	418 lbs.	330 lbs.	380 lbs.
Weight of Ashes left	7·5 lbs.	8 lbs.	10·5 lbs.
Per centage of combustible matter in Ashes	37·32	25·52	32·41
Weight of Cinder left	19 lbs.	15 lbs.	17 lbs.
Per centage of combustible matter in Cinder	44·58	55·57	42·31
Weight of Clinker in Cinder	11·14 lbs.	9 lbs.	10 lbs.
Average weight of Soot in Flues	1·37 lbs.	1·37 lbs.	1·37 lbs.
Per centage of combustible matter in Soot	43·73	..	..
Weight of Water evaporated	2853 lbs.	2660 lbs.	2894 lbs.
Weight of Water evaporated from 212° by 1 lb. of Coal	8·76 lbs.	9·04 lbs.	8·97 lbs.
Weight of Coals per hour for 1 square foot of grate surface	10·2 lbs.	8·24 lbs.	9·48 lbs.
Duration of Experiment	8 hrs.	8 hrs.	8 hrs.
Specific gravity of Coal	1·10	..	..
Mean weight of Cubic foot of Coal	65·08 lbs.	..	..
Economic weight or space occupied by 1 ton	34·41 c. f.	..	..
Cohesive power of Coal	70	..	..

Grangemouth Coals.

I hereby certify that the three casks, addressed "John Wilson, Esq., College, Civil Engineers, Putney," contain a fair sample of the Grangemouth Coal Company's Main Coals, which were mined specially for the service of the "Admiralty Coals Investigation."—Geo. G. Mackay, *Manager*.

This coal is called the main coal, or Carronhall splint, and is mined in the parish of Bothkennar, half a mile from Grangemouth. It is worked long-wall, at the depth of 270 feet from the surface, and varies from 3 feet to 3 feet 4 inches in thickness. The dip of the bedding is from 1 in 10 to 1 in 12, and the subjacent and overlying strata are composed of shale, faike, or laminated sand-stone, coal, fire-clay, and sand-stone. The character given of the coal is, "that it is composed chiefly of splint, with a portion of cherry or cubical coal on the top; that it burns with an intense heat without caking; that it is free from sulphur, and leaves a light-coloured ash." The distance from the port, Grangemouth, is half a mile, and the current price is 9*s.* per ton. The principal markets are the Baltic and France for steam purposes, and the neighbouring districts for iron-smelting, &c.

The sample of coal sent us was from the main coal south working of the Grangemouth Colliery; it is a coal of a dull appearance, and so hard as to require a sledge-hammer to break it up, but splits readily in the direction of the bedding. Across that line the fracture is very irregular: it contains large quantities of a very hard shaly matter, varying in thickness up to 3 and 4 inches, and sometimes intermixed with thin laminæ of bright black coal; the shaly matter burns and leaves a dense whitish residuum. The coal in appearance shows but little pyrites, but numerous plates of a white substance, of a greater thickness than has been observed in any other coal; it always contains a considerable quantity of the soft friable substance which gives such a curious silk-like play to reflected light.

Our remarks during the trials would show that it lights up readily, and although it makes a smoky fire, still but little smoke was seen escaping from the chimney, save when the draught was altered at the time of firing. The pure coal swells and breaks up well on the fire, but the shaly matter splits and flies on the application of heat. On the first day of the trials, towards the latter part of the day, on the ashpit being opened, a large quantity of flame and smoke was forced down through the fire-bars, escaping out of the ashpit-door into the boiler-house; this occurred twice the same day, but not on either of the subsequent days. The ashes were very small, like dust, and of a whitish colour, the cinders and clinker were also of the same colour.

——	February 15, 1st day.	February 16, 2nd day.	February 17, 3rd day.
Fire lighted	8h. 40m.	8h.	8h. 10m.
Steam up	9h. 15m.	8h. 25m.	8h. 35m.
Weight of Wood used	10 lbs.	10 lbs.	10 lbs.

——	February 15, 1st day.	February 16, 2nd day.	February 17, 3rd day.
Initial Temperature of Water in Boiler	191°	216°	216°
Temperature of Water in Tanks	43°	43°	44°
Barometer	29·43 in.	29·84 in.	29·95 in.
Extremes of external Thermometer	..	37°—45°	43°—47°
Extremes of internal Thermometer	45°—58°	46°—58°	52°—61°
Dew-point	50°	48°	52°
Area of Damper open	140 in.	84 in.	84 in.
Weight of Coals consumed	443 lbs.	386 lbs.	402 lbs.
Weight of Ashes left	8 lbs.	7 lbs.	9 lbs.
Per centage of combustible matter in Ashes	45·45	14	34·05
Weight of Cinder left	12 lbs.	11 lbs.	12 lbs..
Per centage of combustible matter in Cinder	46·22	63·4	41·66
Weight of Clinker in Cinder	3·14 lbs.	4 lbs.	2 lbs.
Average Weight of Soot in Flues	1·9 lb.	1·9 lb.	1·9 lb.
Per centage of combustible matter in Soot	46·43	..	..
Weight of Water evaporated	2857 lbs.	2398 lbs.	2530 lbs.
Weight of Water evaporated from 212° by 1 lb. of Coal	7·72 lbs.	7·2 lbs.	7·29 lbs.
Weight of Coals per hour for 1 square foot of grate surface	11·07 lbs.	9·63 lbs.	10·03 lbs.
Duration of Experiment	8 hrs.	8 hrs.	8 hrs.
Specific gravity of Coal	1·29	..	..
Mean weight of cubic foot of Coal	54·25 lbs.	..	..
Economic weight or space occupied by 1 ton	40·13 c. f.	..	..
Cohesive power of Coal	69·7	..	..

Broomhill Coals.

I hereby certify that the ten boxes, marked Nos. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, contain a fair sample of the Broomhill Colliery coals, which were mined especially for the service of the "Admiralty Coals Investigation."—Francis Carr, *Manager.*

This colliery is situated at Broomhill, on the Chevington estate of the Earl Grey, and lies about 24 miles N.N.E. from Newcastle, 9 miles N.N.E. from Morpeth, 9½ miles S.S.E. from Alnwick, and 3 miles S. from Warkworth, which is the port at which the coal is shipped. There are two workable pits: the one now in work is called the "Low Main Coal Seam," which is worked at a depth of 204 feet from the surface, and averages about 5 feet 10 inches in thickness, all clean coal, save a thin piece of splint coal at the top of the seam. It is worked "board and pillar," in contradistinction from "long work." The dip is about 1 in 12, or 4¾°, and runs about S. 44° E. The overlying strata appear to be clay, an argillaceous blue stone, and a gray coloured sand-stone, very strong and hard, which is also continued underneath the present workings.

The character of the coal given is, "bituminous, open burning, leaves little earthly residue, is a prime steam coal, being of a very quick and intense heating power." The current price is 3*s.* 4*d.* per ton at the pit, the sale at present being confined to the neighbouring markets. In the general remarks it is stated, "That the extent of the coal field is estimated at 5000 acres: that there are two other good marketable seams, the High Main Seam, 4 feet

9 inches thick, at a depth of 102 feet, and the Yard Coal Seam, 3 feet 2 inches thick, at a depth of 246 feet, all running parallel to each other over a great part of the said area. There is scarcely any fire-damp or carb. hydrogen."

The sample of Broomhill coal sent up for examination showed that the coal was of a very hard description, but readily splitting in the planes of deposition. The structure of the coal varied considerably; hard thin plates of very bright black coal, having, when broken, somewhat of a conchoidal fracture, alternating with hard dull-looking shaly laminæ, and patches of soft friable material, having the silky appearance so often observed. There appeared to be a very considerable quantity of pyrites in the jointings, which, though in thickness considerable enough to show distinct crystals, did not appear to exist disseminated through the entire mass. Small patches of white matter were also seen in detached plates.

Our remarks during the experiments are, that this coal lights up very readily, burns briskly, with a crackling noise, and makes a very dirty fire, with a dull flame; yet, when the draught is well arranged, but little smoke escaped from the chimney. The ashes and cinders were of a whitish colour, and the clinkers left in very small pieces.

——	March 1, 1st day.	March 2, 2nd day.	March 5, 3rd day.
Fire lighted	8h.	8h. 15m.	8h.
Steam up	8h. 45m.	8h. 55m.	8h. 40m.
Weight of Wood used	10 lbs.	10 lbs.	10 lbs.
Initial Temperature of Water in Boiler	172°	216°	163°
Temperature of Water in Tanks	36°	38°	42°
Barometer	30·37 in.	30·54 in.	30·32 in.
Extremes of external Thermometer	..	32°—38°	39°—41°
Extremes of internal Thermometer	43°—50°	47°—55°	48°—53°
Dew-point	40°	42°·5	43°
Area of Damper open	140 in.	84 in.	84 in.
Weight of Coals consumed	520 lbs.	360 lbs.	432 lbs.
Weight of Ashes left	5 lbs.	6 lbs.	5·5 lbs.
Per centage of combustible matter in Ashes	38·56	69·9	59·97
Weight of Cinder left	7 lbs.	6 lbs.	6 lbs.
Per centage of combustible matter in Cinder	48·21	38·43	49·94
Weight of Clinker in Cinder	3·6 lbs.	·75 lbs.	None.
Average weight of Soot in Flues	2 lbs.	2 lbs.	2 lbs.
Per centage of combustible matter in Soot	55·45	..	..
Weight of Water evaporated	3017 lbs.	2326 lbs.	2519 lbs.
Weight of Water evaporated from 212° by 1 lb of Coal	8·55 lbs.	9·02 lbs.	8·7 lbs.
Weight of Coals per hour for 1 square foot of grate surface	10·83 lbs.	7·5 lbs.	9 lbs.
Duration of Experiment	8 hrs.	8 hrs.	8 hrs.
Specific gravity of Coal	1·25	..	..
Mean weight of cubic foot of Coal	52·5 lbs.	..	..
Economic weight or space occupied by 1 ton	42·67 c. f.	..	..
Cohesive power of Coal	65·7	..	..

Resolven Coals.

We hereby certify that the two casks, marked John Wilson, Esq., contain a fair sample of the Resolven Steam Coals, which were mined specially for the service of the "Admiralty Coals Investigation."—Jevons and Wood, *Agents to J. W. Lyon, Esq.*

This coal is known as the Garrylwyd Seam, and is obtained in the Resolven Wood, in the Vale of Neath. It is worked by level, cross headings and stalls, at a distance from the surface of 600 feet. The dip or inclination is 3 inches in the yard, or 1 in 12, with a westerly direction; the thickness of the seam being 2 feet 6 inches, and rather irregular. The price current is 10*s.* per ton; the principal markets being the Government depôts. The colliery is about 9 miles from the port of Neath.

This sample of coal is very soft, has rather a dull appearance, and breaks up with a very irregular fracture. In many places the structure is distinctly fibrous, and in a few instances the lines tend towards a point assuming a conical form. Where the fibrous structure is well shown, the coal resembles good iron cut across the grain; the cross section often showing circular tables having a brilliant lustre. The bedding is well defined by the brown matter so often met with in coal; but there appears to be a much greater tendency to break in directions inclined to the bedding than parallel to it. The coal is readily broken up into irregular oblique rhombs, and the exposed surfaces contain a considerable quantity of white matter, together with a smaller quantity of pyrites.

During the trials, we found that the coal kindled readily, caking slightly on the dead plate; on the fire it swelled up and soon split, making a strong open fire. The fire was throughout very clear, and only a small quantity of reddish-brown smoke was seen occasionally at the chimney top. The ashes and cinders left were in small quantities, well burnt, and of a whitish appearance. The soot found in the flue was very heavy, and of a light colour, owing to small ashy matter having been carried over and mixed with it.

——	March 15, 1st day.	March 16, 2nd day.	March 17, 3rd day.
Fire lighted	11h. 45m.	8h. 15m.	8h. 15m.
Steam up	12h. 45m.	8h. 30m.	8h. 30m.
Weight of Wood used	10 lbs.	10 lbs.	10 lbs.
Initial Temperature of Water in Boiler	160°	218°	217°
Temperature of Water in Tanks	47°	44°	47°
Barometer	30·23 in.	29·9 in.	29·83 in.
Extremes of external Thermometer	..	48°—52°	46°—56°
Extremes of internal Thermometer	52°—60°	52°—64°	56°—70°
Dew-point	46°	48°·5	50°
Area of Damper open	84 in.	56 in.	56 in.
Weight of Coals consumed	369 lbs.	314 lbs.	·300 lbs.
Weight of Ashes left	7·5 lbs.	7 lbs.	7·5 lbs.
Per centage of combustible matter in Ashes	78·7	53·46	42·86
Weight of Cinder left	9 5 lbs.	5 lbs.	7 lbs.
Per centage of combustible matter in Cinder	63·68	70·78	71·31
Weight of Clinker in Cinder	None.	..	..

—	March 15, 1st day.	March 16, 2nd day.	March 17, 3rd day.
Average weight of Soot in Flues	1 lb.	1 lb.	1 lb.
Per centage of combustible matter in Soot	41	..	..
Weight of Water evaporated	2521 lbs.	2857 lbs.	2481 lbs.
Weight of Water evaporated from 212° by 1 lb. of Coal	8·53 lbs.	10·52 lbs.	9·54 lbs.
Weight of Coals per hour for 1 square foot of grate surface	9·24 lbs.	7·44 lbs.	7·5 lbs.
Duration of Experiment	8 hrs.	8 hrs.	8 hrs.
Specific gravity of Coal	1·32	..	..
Mean weight of cubic foot of Coal	58·66 lbs.	..	..
Economic weight or space occupied by 1 ton	38·19 c. f.	..	..
Cohesive power of Coal	35	..	..

Summary.

Names of Coals employed in the Experiments.	Evaporating power, or number of pounds of Water evaporated from 212° by 1 lb. of Coal (economic).	Weight of 1 cubic foot of the Coal as used for fuel.—Lbs.	Weight of 1 cubic foot of the Coal as calculated from the density.—Lbs.	Ratio of B. to C., or of the economical to the theoretical weight.	Difference per cent. between theoretical and economical weights.	Space occupied by 1 ton in cubic feet (economic weight).	Results of experiments on cohesive power of coals per centage of large Coals.	Evaporating power of the Coal, after deducting for the combustible matter in the residue.	Per centage of residue in the Coals.—Mean.
	A.	B.	C.	D.	E.	F.	G.	H.	I.
Pentrefelin	6·36	66·166	84·726	·781	28·051	33·85	52·7	7·4	27·7
Dyffryn	10·149	53·22	82·72	·643	55·43	42·09	56·2	11·80	7·81
Old Castle Fiery Vein	8·94	50·916	80·42	·633	57·946	43·99	57·7	..	6·57
Binea	9·446	57·08	81·357	·702	42·53	39 24	51·2	10·3	8·22
Mynydd Newydd	9·52	56·33	81·73	·689	45 09	39·76	53·7	10·59	8·28
Resolven	9·53	58·66	82·354	·712	40·39	38·19	35·0	10 44	4 71
Anthracite, Jones and Co.	9·46	58·25	85·786	·679	47·26	38·45	68·5	9·7	9·58
Ward's Fiery Vein	9·4	57·433	83·85	·685	46·	39·	46·5	10·6	7·44
Llangennech	8·86	56·93	81·85	·695	43·76	39·34	53·5	9·2	11·04
Three-quarter Rock Vein	8·84	56·388	83·60	·674	48·26	39·72	52·7	..	7·36
Graigola	9·35	60·166	81·107	·742	34·8	37·23	49·3	9·66	9·27
Lydney (Forest of Dean)	8·52	54·444	80·046	·68	47·02	41·24	55·0	8·98	4·06
Pentreporth	8·72	57·72	81·73	·705	40·17	38·80	46·5	8·98	10·47
Cwm Ffrood Rock Vein	8·70	55·277	78·299	·706	41·648	40·52	72·5	9·35	7·8
Cwm Nanty-Gros	8·42	56·0	79·859	·701	42·60	40·00	55·7	8·82	5·44
Wylam's Patent Fuel	8·92	65·08	68·629	·948	5·45	34·41	70·0	9·74	7·27
Grangemouth	7·4	54·25	80·48	·674	48·35	40·13	69·7	7·91	5·26
Broomhill	7·3	52·5	77·988	·673	48·55	42·67	65·7	7·66	3·23

Section II.—*On the Evaporating Powers of Coal.* By Mr. J. Arthur Phillips.

Pontypool Coals.

I hereby certify that the four casks, marked Nos. 120, 121, 122, 123, contain a fair sample of Morrison's Pontypool Rock Vein Coals, which were mined specially for the service of the "Admiralty Coals Investigation."—Richard Morrison, *Proprietor.*

This colliery is situated near Pontypool, in the county of Monmouth, at the distance of about 10 miles from the shipping port, from whence the coals

are exported to France, Spain, Portugal, the Mediterranean, South America, Brazils, and the West Indies. The current price is 9*s.* 6*d.* per ton.

The seam is very regular, and 8 feet in thickness. The coal is worked by level, at a depth of about 150 yards from the surface. The subjacent and overlying strata being shale, which, together with the seam itself, has an inclination of 3½ inches in the yard towards the west.

The sample of this coal which was sent up for trial, was hard and brilliant, with lines of fracture parallel to the bedding, and appeared to be considerably mixed with shale, which formed layers, very distinctly visible, parallel to the planes of deposition. This coal also contains a rather large amount of iron pyrites, which appeared to be pretty regularly disseminated throughout the mass.

It was remarked, during the experiments, that the fire lighted easily, and got the steam up rapidly, but that considerable quantities of smoke were evolved during the whole time of experiment.

This coal cokes slightly on the dead-plate, and the fire requires constant attention.

—	July 7, 1st day.	July 8, 2nd day.	July 9, 3rd day.
Fire lighted	5h. 40m.	8h.	8h. 15m.
Steam up	6h.	8h. 20m.	8h. 25m.
Weight of Wood used	10 lbs.	10 lbs.	10 lbs.
Initial Temperature of Water in Boiler	204°	209°	209°
Temperature of Water in Tanks	73°	68°	70°
Barometer	29·9 in.	29·98 in.	30·15 in.
Extremes of external Thermometer	64°—73°	56°—70°	62°—73°
Extremes of internal Thermometer	72°—74°	68°—72°	56°—71°
Dew-point	..	..	..
Area of Damper open	112 in.	56 in.	84 in.
Weight of Coals consumed	304 lbs.	252 lbs.	242 lbs.
Weight of Ashes left	9 lbs.	8 lbs.	15 lbs.
Per centage of combustible matter in Ashes	1·23	17·06	10·22
Weight of Cinder left	14 lbs.	30 lbs.	20 lbs.
Per centage of combustible matter in Cinder	23·27	75·74	86·59
Weight of Clinker in Cinder	4 lbs.	1·2 lbs.	..
Average weight of Soot in Flues	0·6 lbs.	0·6 lbs.	0·6 lbs.
Per centage of combustible matter in Soot	76·0	..	..
Weight of Water evaporated	2205 lbs.	1616 lbs.	1469 lbs.
Weight of Water evaporated from 212° by 1 lb of Coal	8·32 lbs.	7·25 lbs.	6·84 lbs.
Weight of Coals per hour for 1 square foot of grate surface	7·6 lbs.	6·3 lbs.	6·03 lbs.
Duration of Experiment	8h. 5m.	8h. 10m.	8h.
Specific gravity of Coal	1·32	..	..
Mean weight of cubic foot of Coal	55·7 lbs.	..	..
Economic weight or space occupied by 1 ton	40·216 c. f.	..	..
Cohesive power of Coal	57·5	..	..

Note.—Final temperature on fourth morning, 209°.

Bedwas Coal.

I hereby certify that the three casks, marked Bedwas Vein Coals, contain a fair sample of the said Bedwas coals, which were mined specially for the service of the "Admiralty Coals Investigation."—Joseph Jones, *Proprietor.*

This coal is mined in the parish of Bedwas, county of Monmouth, and is situated at about 10½ miles from the shipping port. The principal markets for these coals are Spain, Portugal, different ports of the Mediterranean, and in England.

The colliery was opened about eighteen months since, and appears to improve as the workings advance. The coals are at present extracted from a depth of about 30 yards, by means of a steam-engine. The thickness of the seam is 2 feet 8 inches, and the subjacent strata hard fire-clay ; it is overlaid by a stratum of rock, which varies from 15 to 20 yards in thickness.

The seam has an inclination of from 4 to 5 inches in the yard towards the south.

The current price of this coal is 9*s.* 6*d.* per ton ; and the character given of it by the proprietor is, "Large, hard, and free burning ; free from sulphur and earthy matters, and much liked for steam purposes."

The specimen of these coals on which the experiments were made was firm and brilliant, with a cubical fracture ; it contained iron pyrites, but in smaller quantities than the last.

It was remarked, during the progress of these experiments, that this coal produced but little smoke, and burned freely, with the formation of but little clinker. It also ignites easily, and gets up the steam rapidly.

——	August 2, 1st day.	August 3, 2nd day.	August 4, 3rd day.
Fire lighted	8h.	8h. 50m.	8h. 15m.
Steam up	8h. 50m.	9h.	8h. 33m.
Weight of Wood used	10 lbs.	10 lbs.	10 lbs.
Initial Temperature of Water in Boiler	168°	212°	212°
Temperature of Water in Tanks	74°	73°	69°
Barometer	30·0 in.	30·10 in.	29·9 in.
Extremes of external Thermometer	70°—82°	74°—50°	75°—88°
Extremes of internal Thermometer	70°—79°	70°—75°	69°—75°
Dew-point	55°	46°	54°
Area of Damper open	112 in.	56 in.	84 in.
Weight of Coals consumed	43 lbs.	350 lbs.	390 lbs.
Weight of Ashes left	6 lbs.	6 lbs.	6 lbs.
Per centage of combustible matter in Ashes	38·53	33·84	20·79
Weight of Cinder left	11 lbs.	7 lbs.	8 lbs.
Per centage of combustible matter in Cinder	60·74	49·44	49·61
Weight of Clinker in Cinder	5·6 lbs.	2·3 lbs.	5·3 lbs.
Average weight of Soot in Flues	..	..	..
Per centage of combustible matter in Soot	..	..	..
Weight of Water evaporated	3620 lbs.	3200 lbs.	3420 lbs.
Weight of Water evaporated from 212° by 1 lb. of Coal	9·0 lbs.	10·4 lbs.	9·98 lbs.

—	August 2, 1st day.	August 3, 2nd day.	August 4, 3rd day.
Weight of Coals per hour for 1 square foot of grate service	10·87 lbs.	8·75 lbs.	9·75 lbs.
Duration of Experiment	8 hrs.	8 hrs.	8 hrs.
Specific gravity of Coal	1·32	..	..
Mean weight of cubic foot of Coal	50·5 lbs.	..	..
Economic weight or space occupied by 1 ton	44·32 c. f.	..	..
Cohesive power of Coal	54	..	..

Note.—Final temperature on fourth morning 212°.

Porthmawr Rock Vein Coal.

I hereby certify that the two casks, marked P M C C°., contain a fair sample of the Porthmawr Rock Vein coals, which are mined specially for the service of the "Admiralty Coals Investigation."—Reginauld Blewett, *Proprietor.*

The Porthmawr colliery is situated at a distance of about eight miles from Newport, Monmouthshire, and the coals are shipped from that port to nearly all parts of the world. Its current price is from 9*s.* to 9*s.* 6*d.* per ton. They are said by the proprietor to be "excellent for steam purposes, and the manufacture of iron in all its stages."

The thickness of the seam varies from 5 to 6 feet, and is generally tolerably regular.

The coals are obtained by means of a level or horizontal gallery. The subjacent, like the overlying strata, are composed of rock and shale, which have an inclination of about six feet in the yard from N.E. to S.W.

The sample of this coal on which the experiments were made was very irregular in its cleavage, and appeared to be mixed with a considerable quantity of shale, which was disseminated in the coal, without regard to stratification. During the experiments, and throughout their continuance, a large amount of smoke was evolved. The fire, however, lighted easily, burned freely, and got the steam up rapidly; but considerable quantities of ash remained at the close of each experiment.

—	August 25, 1st day.	August 27, 2nd day.	August 28, 3rd day.
Fire lighted	8h. 15m.	10h. 15m.	7h.
Steam up	8h. 55m.	10h. 50m.	7h. 20 m.
Weight of Wood used	10 lbs.	10 lbs.	10 lbs.
Initial Temperature of Water in Boiler	167°	204°	207°
Temperature of Water in Tanks	65°	72°	72°
Barometer	30·15 in.	30·20 in.	30·12 in.
Extremes of external Thermometer	62°—70°	68°—75°	66°—76°
Extremes of internal Thermometer	62°—68°	70°—75°	68°—76°
Dew-point	46°	55°	52°
Area of Damper open	112 in.	56 in.	84 in.
Weight of Coals consumed	451 lbs.	248 lbs.	422 lbs.
Weight of Ashes left	21 lbs.	16 lbs.	18 lbs.

——	August 2, 1st day.	August 3, 2nd day.	August 4, 3rd day.
Per centage of combustible matter in Ashes	45·21	25·42	28·85
Weight of Cinder left	13·5 lbs.	11 lbs.	12 lbs.
Per centage of combustible matter in Cinder	40·61	21·98	29·93
Weight of Clinker in Cinder	6·5 lbs.	2 lbs.	5 lbs.
Average weight of Soot in Flues	1·3 lbs.	1·3 lbs.	1·3 lbs.
Per centage of combustible matter in Soot	83·34	..	..
Weight of Water evaporated	3090 lbs.	1750 lbs.	2700 lbs.
Weight of Water evaporated from 212° by 1 lb. of Coal	7·26 lbs.	8·05 lbs.	7·27 lbs.
Weight of Coals per hour for 1 square foot of grate surface	11·27 lbs.	6·20 lbs.	10·55 lbs.
Duration of Experiment	8 hrs.	8 hrs.	8 hrs.
Specific gravity of Coal	1·39	..	..
Mean Weight of cubic foot of Coal	53·3 lbs.	..	..
Economic weight or space occupied by 1 ton.	42·02 c. f.	..	..
Cohesive power of Coal	62	..	..

Note.—Final temperature on fourth morning 207°.

Warlich's Patent Fuel.

I hereby certify that the 362 bricks of Warlich's Patent Fuel, weighing two tons, which were made specially for the service of the "Admiralty Coals Investigation," are a fair sample.—T. C. Warlich, *Proprietor.*

This fuel is sold in bricks which have the following dimensions: length 9 inches, breadth $6\frac{1}{2}$ inches, thickness 5 inches, which would give 252·5 inches as the cubic contents of each block; but on taking the mean of 40 blocks they were found to average only 0·177 of a cubic foot. The economic weight of a cubic foot is 69·05 lbs.

This fuel is manufactured from the Resolven coal dust, which is bought at 3*s.* per ton for this purpose. This dust on arriving in the port of London is generally very wet, and occupies, when converted into fuel, about 30 cubic feet to the ton.

The specimen experimented on was remarkably dense and well made, being almost as solid and difficult to break as a common brick.

It was observed during the experiments that it gives off but little smoke in burning, and that the little evolved is of a grayish colour. It, however, takes considerable time to light, and consequently does not get up the steam so rapidly as some kinds of free-burning coal.

Experience also proves that this fuel burns best when broken into fragments of about six ounces in weight, otherwise it has a tendency to cake on the bars and choke the draught.

—	August 11, 1st day.	August 12, 2nd day.	August 13, 3rd day.
Fire lighted	8h. 45m.	9 hrs.	9 hrs.
Steam up	9h. 30m.	9h. 50m.	9h. 25m.
Weight of Wood used	10 lbs.	10 lbs.	10 lbs.
Initial Temperature of Water in Boiler	184°	212°	212°
Temperature of Water in Tanks	70°	74°	73°
Barometer	30·19 in.	30·25 in.	30·29 in.
Extremes of external Thermometer	60°—75°	63°—85°	55°—76°
Extremes of internal Thermometer	69°—75°	74°—80°	74°—80°
Dew-point	56°	68°	55°
Area of Damper open	112 in.	56 in.	84 in.
Weight of Coals consumed	441 lbs.	247 lbs.	371 lbs.
Weight of Ashes left	6 lbs.	14 lbs.	11 lbs.
Per centage of combustible matter in Ashes	25·43	35·68	15·68
Weight of Cinder left	8 lbs.	8 lbs.	6 lbs.
Per centage of combustible matter in Cinder	61·76	59·0	77·93
Weight of Clinker in Cinder	7 lbs.	2 lbs.	5 lbs.
Average weight of Soot in Flues	..	..	..
Per centage of combustible matter in Soot	..	..	..
Weight of Water evaporated	3860 lbs.	2220 lbs.	3460 lbs.
Weight of Water evaporated from 212° by 1 lb. of Coal	10·32 lbs.	10·11 lbs.	10·62 lbs.
Weight of Coals per hour for 1 square foot of grate surface	11·02 lbs.	6·17 lbs.	9·27 lbs.
Duration of Experiment	8 hrs.	8 hrs.	8 hrs.
Specific gravity of Coal	1·15	..	..
Mean weight of cubic foot of Coal	69·05 lbs.	..	..
Economic weight or space occupied by 1 ton.	32·44 c. f.	..	..
Cohesive power of Coal	..	..	..

Note.—Final temperature on fourth morning 212°.

Ebbw Vale Coals.

I hereby certify that the four casks, marked E. V., contain a fair sample of the Ebbw Vale Four-feet Steam Coals, which were mined specially for the service of the "Admiralty Coals Investigation."—Signed by the Ebbw Vale Company.

This is generally known by the name of the Ebbw Vale Four-feet Steam Coals, and is raised at the Ebbw Vale iron works, 21 miles from Newport, where it is shipped. The principal markets are the Mediterranean, the West Indies, and the Brazils. The present price is 10*s.* per ton.

The proprietors recommend it very strongly as "containing little sulphur," and represent it as being "much in demand for marine and other steam purposes." The mine is from 400 to 500 feet in depth, and the seam from which the coal is raised varies from 3 feet 6 inches to 4 feet 6 inches in thickness, and has an inclination of 1 in 12 towards the south.

The subjacent and overlying strata are of sandstone. The sample mined for the service of the investigation is excessively brilliant, with a cubical fracture, but rather friable, and contains little iron pyrites.

It was remarked during the experiments that they lighted easily, and got up the steam quickly, yielding a fine clear fire. They cake on the bars, but produce very little clinker, and an extremely small quantity of red ash, which

is almost totally consumed when again thrown on the fire. They were also found to evolve a grayish-black smoke in rather considerable quantity, especially after stirring the fire, and from their bituminous nature require frequent stirring.

It may also be remarked that they were tried for the purpose of forging iron, and found to answer extremely well.

——	September 6, 1st day.	September 7, 2nd day.	September 9, 3rd day.
Fire lighted	9hrs.	9h. 15m.	10h. 25m.
Steam up	9h. 45m.	9h. 50m.	11h. 15m.
Weight of Wood used	10 lbs.	10 lbs.	10 lbs.
Initial Temperature of Water in Boiler	172°	202°	190°
Temperature of Water in Tanks	55°	63°	59°
Barometer	29·95 in.	30·02 in.	30·15 in.
Extremes of external Thermometer	40°—57°	54°—60°	51°—65°
Extremes of internal Thermometer	57°—69°	60°—65°	66°—71°
Dew-point	45°	..	..
Area of Damper open	112 in.	56 in.	84 in.
Weight of Coals consumed	445 lbs.	319 lbs.	320 lbs.
Weight of Ashes left	7 lbs.	13 lbs.	8 lbs.
Per centage of combustible matter in Ashes	92·0	94·2	83·9
Weight of Cinders left	8·8 lbs.	10·0 lbs.	9 lbs.
Per centage of combustible matter in Cinder	97·5	14·1	74·6
Weight of Clinker in Cinder	1·3 lbs.	None.	3·2 lbs.
Average weight of Soot in Flues	2 lbs.	2 lbs.	2 lbs.
Per centage of combustible matter in Soot	57·9	..	..
Weight of Water evaporated	3620 lbs.	2700 lbs.	3120 lbs.
Weight of Water evaporated from 112° by 1 lb. of Coal	10 lbs.	9·44 lbs.	11·20 lbs.
Weight of Coals per hour for 1 square foot of grate surface	11·12 lbs.	7·97 lbs.	8·1 lbs.
Duration of Experiment	8 hrs.	8 hrs.	8 hrs.
Specific gravity of Coal	1·275	..	..
Mean weight of cubic foot of Coal	53·33 lbs.	..	..
Economic weight or space occupied by 1 ton.	42·26 c. f.	..	..
Cohesive power of Coal	45·0	..	..

Note.—Final temperature on fourth morning 190°.

Fordel Splint Coal.

I hereby certify that the two casks, marked F, S, C, contain a fair sample of the Fordel Splint Coals, which were mined specially for the service of the "Admiralty Coals Investigation."—(Signed) Alexander Lyell, *Agent for George Mercer Henderson, Proprietor.*

The colliery from which this coal is extracted is situated in the parish of Dalgety, in the county of Fife, and is from five to six miles from the shipping port, where its current price is 9*s.* per ton. It is raised from what is called the Splint Seam, at a depth of from 50 to 80 fathoms from the surface.

This vein is generally from 4 to 4½ feet in thickness, and has an inclination of from 16° to 20° towards the north-east. It is worked by stoop and round, or Shropshire method, and is generally pretty regular. The proprietor describes this coal as "hard, bituminous, and lively in burning."

The specimen which came into our hands was lamellar in structure, with oblique cross partings: it consisted of very brilliant layers, interspersed with less shining laminæ, which resemble mineralized charcoal. This coal is extremely hard, but, when broken, divides into rhombic fragments. Spots of pyrites sometimes occur, but not in any considerable quantity.

During the experiments it was observed that they light up easily, and give a strong flame. They also require but little stoking, it being only necessary to push the coked coals forward from the dead-plate, and replace them by fresh coals, in order to maintain a good clear fire: they were also found to produce a considerable quantity of grayish smoke, but leave little ash or clinker.

—	September 15, 1st day.	September 17, 2nd day.	September 18, 3rd day.
Fire lighted	8h. 45m.	9h. 40m.	8h. 30m.
Steam up	10h.	10h. 10m.	8h. 45m.
Weight of Wood used	10 lbs.	10 lbs.	10 lbs.
Initial Temperature of Water in Boiler	118°	203°	207°
Temperature of Water in Tanks	63°	62°	62°
Barometer	29·95 in.	29·95 in.	30·15 in.
Extremes of external Thermometer	52°—62°	45°—54°	45°—62°
Extremes of internal Thermometer	61°—66°	64°—70°	63°—66°
Dew-point	54°	55°	53°
Area of Damper open	112 in.	56 in.	84 in.
Weight of Coals consumed	597 lbs.	413 lbs.	465 lbs.
Weight of Ashes left	5 lbs.	7 lbs.	8 lbs.
Per centage of combustible matter in Ashes	45·9	68·7	64·8
Weight of Cinder left	4·5 lbs.	7 lbs.	4·5 lbs.
Per centage of combustible matter in Cinder	77·78	59·40	68·8
Weight of Clinker in Cinder	1·5 lbs.	None.	0·3 lbs.
Average weight of Soot in Flues	1 lb.	1 lb.	1 lb
Per centage of combustible matter in Soot	70·0	..	..
Weight of Water evaporated	3625 lbs.	2870 lbs.	3060 lbs.
Weight of Water evaporated from 212° by 1 lb. of Coal	7·78 lbs.	8·04 lbs.	6·87 lbs.
Weight of Coals per hour for 1 square foot of grate surface	14·92 lbs.	10·32 lbs.	11·62 lbs.
Duration of Experiment	8 hrs.	8 hrs.	8 hrs.
Specific gravity of Coal	1·25	..	..
Mean weight of cubic foot of Coal	55·0 lbs.	..	..
Economic weight or space occupied by 1 ton	40·72 c. f.	..	..
Cohesive power of Coal	63·0	..	..

Note.—Final temperature on fourth morning 150°.

Coleshill Coal.

I hereby certify that the 85 tons of coals, shipped per schooner "Brothers," addressed to the Superintendents of Her Majesty's Dockyard, Woolwich, are a fair sample of the Coleshill Coal Company's coals, which were mined specially for the service of the "Admiralty Coals Investigation."—(Signed) William Maxwell, *Agent for the Coleshill Company.*

This pit is situated at the distance of about one mile from the village of Bagilt, on the river Dee, from whence the coal is shipped for different parts

of Great Britain, and more particularly for the Irish and Welsh coasts. The current price is 8*s.* 6*d.* per ton, and it is described by the agent as "free burning, strongly bituminous, and leaving very little of a white ash." He further adds, "This coal is extensively used by the Steam Navigation Company of Liverpool, as also by the various lead-smelting establishments on the river Dee, and is highly approved of.

The coal is extracted from a depth of 80 yards from the surface, and the seam, which is 5 feet 9 inches in thickness, is generally pretty regular. It has an easterly dip of 1 in 5, and is worked by stalls 7 yards in width. The overlying and adjacent strata are rock and shale.

The specimen of this coal, which was sent us from Her Majesty's Dockyard at Woolwich, was in rather small fragments, and appears to crumble easily into rhombic fragments, which are apt to fall through the fire-bars. It, however, lights easily and burns freely, producing a considerable quantity of black smoke, which escapes during the whole time of combustion, but more particularly immediately after charging the grate. After the experiment large quantities of ash mixed with shale and scoria remained.

Note.—It was also observed that the coals did not appear to be carefully picked, as large masses of black and blue shale were observed to be mixed with them.

——	October 7, 1st day.	October 8, 2nd day.	October 9, 3rd day.
Fire lighted	9h. 15m.	9h. 30m.	9h. 30m.
Steam up	9h. 45m.	9h. 45m.	9h. 50m.
Weight of Wood used	10 lbs.	10 lbs.	10 lbs.
Initial Temperature of Water in Boiler	200°	209°	205°
Temperature of Water in Tanks	60°	56°	58°
Barometer	29·67 in.	30·0 in.	30·05 in.
Extremes of external Thermometer	43°—57°	50°—63°	51°—62°
Extremes of internal Thermometer	61°—66°	63°—67°	65°—68°
Dew-point	57°	..	58°
Area of Damper open	112 in.	56 in.	84 in.
Weight of Coals consumed	405 lbs.	283 lbs.	332 lbs.
Weight of Ashes left	9 lbs.	9 lbs.	11 lbs.
Per centage of combustible matter in Ashes	35·1	44·9	26·0
Weight of Cinder left	10 lbs.	10 lbs.	7 lbs.
Per centage of combustible matter in Cinder	5·82	57·2	63·6
Weight of Clinker in Cinder	8 lbs.	4 lbs.	6 lbs.
Average weight of Soot in Flues	1·5 lbs.	1·5 lbs.	1·5 lbs.
Per centage of combustible matter in Soot	71·5	..	..
Weight of Water evaporated	2650 lbs.	2160 lbs.	2270 lbs.
Weight of Water evaporated from 212° by 1 lb of Coal	7·67 lbs.	8·67 lbs.	7·68 lbs.
Weight of Coals per hour for 1 square foot of grate surface	11·57 lbs.	8·08 lbs.	11·06 lbs.
Duration of Experiment	7 hrs.	7 hrs.	6 hrs.
Specific gravity of Coal	1·29	..	..
Mean weight of cubic foot of Coal	53 lbs.	..	..
Economic weight or space occupied by 1 ton	42·26 c. f.	..	..
Cohesive power of Coal	62·0	..	..

Note.—Final temperature on fourth morning 190°.

SLIEVARDAGH COAL.

I hereby certify, that the three casks and one box, marked Coals from the Slievardagh Collieries, contain a fair sample of the Slievardagh coals, from the county of Tipperary, which were mined specially for the service of the "Admiralty Coals Investigation."—(Signed) WILLIAM BULLEN, *Part Proprietor and Agent.*

This coal-field is situated in the barony of Slievardagh, in the county of Tipperary, Ireland. It lies between the towns of Cullen and Willingford, being seven miles distant from the former, and about three from the latter place. The nearest shipping port is Carrick-on-Suir: but as soon as the railways are completed, the communication will be opened to the Shannon and Cork harbour. The thickness of the vein is 3 feet, and the coals employed in the experiments were extracted from a depth of about 25 yards from the surface, by means of a whim, though a tunnel is now in progress, in which a tramroad is to be laid, so as to enable the coal to be removed directly from the seam by means of horses. The vein itself has an inclination of 1 in 5, and is situated in soft slate and sandstone, both easily worked. This coal is at present chiefly sold in the surrounding country and neighbouring towns, and fetches at the pit's mouth from 1*l.* to 1*l.* 5*s.* per ton.

The specimen of this coal which came into our hands was highly anthracitic, and it was therefore determined to make the experiment of three times the usual length, in order to avoid the inconvenience and loss of heat which would have attended the frequent lighting and extinction of a coal which, though difficult to light, would, when once burning, take several hours to become extinct.

In order to light the fire, 50 lbs. of the Coleshill coals were employed, for which allowance was of course made in the calculations. It was observed during the experiments that this coal requires a strong draught, and that the fire requires to be well supplied with fuel, which should be previously heated on the dead-plate to prevent decrepitation. When these precautions were attended to, a beautifully clear fire, without smoke, was obtained, which left no soot in the flues. The fire took seven hours to become extinguished at the close of the experiment.

——	October 13.
Fire lighted	8h. 40m.
Steam up	10h. 30m.
Weight of Water used	10 lbs.
Initial Temperature of Water in Boiler	150°
Temperature of Water in Tanks	60°
Barometer	30·05 in.
Extremes of external Thermometer	40°—60°
Extremes of internal Thermometer	64°—70°
Dew-point	53°
Area of Damper open	112 in.
Weight of Coals consumed	1249 lbs.
Weight of Ashes left	21 lbs.
Per centage of combustible matter in Ashes	67·9

——	October 13.
Weight of Cinder left	59 lbs.
Weight of Clinker in Cinder	10 lbs.
Per centage of combustible matter in Cinder	91·5
Average weight of Soot in Flues	None.
Per centage of combustible matter in Soot	..
Weight of Water evaporated	10,980 lbs.
Weight of Water evaporated from 212° by 1 lb. of Coal	9·85 lbs.
Weight of Coals per hour for 1 square foot of grate surface	9·60 lbs.
Duration of Experiment	26 hrs.
Specific gravity of Coal	1·59
Mean weight of cubic foot of Coal	62·8 lbs.
Economic weight or space occupied by 1 ton	35·66 c. f.
Cohesive power of Coal	74

Note.—Final temperature on fourth morning 195°.

Wallsend Elgin Coals.

I hereby certify, that the two casks marked E W, contain a fair sample of the Wallsend Elgin coals, which were mined specially for the service of the " Admiralty Coals Investigation."—(Signed) Robert Menzies, *Agent for the Trustees of the late Earl of Elgin.*

This coal is raised in the lands of Clume and Baldridge, in the parish of Dunfermline, in the county of Fife, at a distance of five miles from the shipping port. Its current price is 9*s.* per ton on board. It is principally used for steam navigation, and steam purposes in general. The seam from which it is extracted is 4½ feet in thickness, and is generally very regular, with an average dip of 1 in 7 towards the north. The subjacent and overlying strata consist of alternate layers of sandstone and coal-slate.

This coal is at present extracted at the depth of 105 fathoms, and is described as " a caking splint of cubical texture, burning freely, with a strong flame."

This coal exactly resembles, in appearance, the Fordel Splint: it was observed during the experiments, that it lighted easily and gave a good fire, which required but little stoking; it has, however, the disadvantage of giving off considerable quantities of a grayish smoke during the whole time of its burning.

——	September 28, 1st day.	September 29, 2nd day.	September 30, 3rd day.
Fire lighted	9 hrs.	9 hrs.	9h. 15m.
Steam up	9h. 20m.	9h. 25m.	9h. 55m.
Weight of Wood used	10 lbs.	10 lbs.	10 lbs.
Initial Temperature of Water in Boiler	204°	210°	195°
Temperature of Water in Tanks	58°	60°	61°
Barometer	30·38 in.	30·29 in.	30·27 in.
Extremes of external Thermometer	40°—59°	45°—60°	45°—59°

——	September 28, 1st day.	September 29, 2nd day.	September 30, 3rd day.
Extremes of internal Thermometer . . .	60°—64°	64°—66°	64°—67°
Dew-point	53°	51°	50°
Area of Damper open	112 in.	56 in.	84 in.
Weight of Coals consumed.	509 lbs.	275 lbs.	461 lbs.
Weight of Ashes left	7 lbs.	5 lbs.	8 lbs.
Per centage of combustible matter in Ashes .	58·8	53·6	40·0
Weight of Cinder left	10·5 lbs.	9 lbs.	6 lbs.
Per centage of combustible matter in Cinder	60·8	58·9	72·1
Weight of Clinker in Cinder	2·3 lbs.	0·8 lbs.	5 lbs.
Average weight of Soot in Flues	1 lb.	1 lb.	1 lb.
Per centage of combustible matter in Soot .	58·2	..	..
Weight of Water evaporated	3640 lbs.	2220 lbs.	3290 lbs.
Weight of Water evaporated from 212° by 1 lb. of Coal	8·33 lbs.	8·85 lbs.	8·21 lbs.
Weight of Coals per hour for 1 square foot of grate surface	12·72 lbs.	6·87 lbs.	11·52 lbs.
Duration of Experiment	8 hrs.	8 hrs.	8 hrs.
Specific gravity of Coal	1·26	..	..
Mean weight of cubic foot of Coal . . .	54·6 lbs.	..	..
Economic weight or space occupied by 1 ton	41·02 c. f.	..	..
Cohesive power of Coal	64	..	..

Note.—Final temperature on fourth morning 195°.

Dalkeith Coronation Seam. Dalkeith Jewel Seam.

The experiments on these two coals were repeated, from the circumstance of their having been tried in the first instance when the brickwork of the boiler was still damp, which circumstance must necessarily have interfered with the results obtained.

During our experiments, it was observed of both these coals, that they lighted easily and burned freely, without the production of much smoke. They also required little stoking, and left but an inconsiderable quantity of incombustible matter.

——	September 10, Coronation Seam.	September 11, Jewel Seam.
Fire lighted	8h. 30m.	11 hrs.
Steam up.	9 hrs.	11h. 40m.
Weight of Wood used	10 lbs.	10 lbs.
Initial Temperature of Water in Boiler . .	180°	193°
Temperature of Water in Tanks	65°	61°
Barometer	30·13 in.	30·15 in.
Extremes of external Thermometer . . .	49°—66°	54°—61°
Extremes of internal Thermometer . . .	70°—72°	68°—70°
Dew-point	49°	56°
Area of Damper open	84 in.	84 in.
Weight of Coals consumed	288 lbs.	301 lbs.
Weight of Ashes left	9 lbs.	6 lbs.
Per centage of combustible matter in Ashes .	18·8	20·5
Weight of Cinder left	7·2 lbs.	5 lbs.
Per centage of combustible matter in Cinder	42	24·8
Weight of Clinker in Cinder	8 lbs.	8 lbs.
Average weight of Soot in flues	..	..

——	September 10, Coronation Seam.	September 11, Jewel Seam.
Per centage of combustible matter in Soot	..	..
Weight of Water evaporated	1900 lbs.	1880 lbs.
Weight of Water evaporated from 212° by 1 lb. of Coal	7·71 lbs.	7·08 lbs.
Weight of Coals per hour for 1 square foot of grate surface	9·60 lbs.	10·30 lbs.
Duration of Experiment	6 hrs.	6 hrs.
Specific gravity of Coal	1·316	1·277
Mean weight of cubic foot of Coal	55·16 lbs.	49·8 lbs.
Economic weight or space occupied by 1 ton	43·36 c. f.	44·98 c. f.
Cohesive power of Coal	88·2	85·7

Note.—Final temperature on third morning 180°.

Bell's Fuel.

No certificate has been received with this fuel.

This fuel is manufactured at Port Talbot, near Taibach, Wales, and is formed in blocks, having the following dimensions:—9″ × 6″ × 5″, which would give 270 cubic inches, or ·015 cubic foot, as the contents of each brick. The economic weight of a cubic foot, as deduced from the measurement of a pile, having the following dimensions: 24 × 21 × 18 inches, was found to be 65·3 lb.

In appearance, this fuel resembled the specimen sent up for trial by Wylam and Co., except that the bricks were smaller and, perhaps, rather more irregular in their texture, some having a compact resinous structure, whilst others easily crumbled under the blow of a hammer.

It was observed that this fuel produced considerable quantities of dense black smoke on lighting the fire, which ceased to be evolved as the experiments progressed. This fuel was found highly bituminous, and to soften slightly even at the temperature of 212° Faht., while at higher temperatures it melted readily, and filaments were frequently observed to run through the fire-bars during the experiments. At the termination of the experiments, considerable quantities of ash and clinker remained, and, during their progress, the fire required very great attention and frequent stoking, in order to prevent the choking of the grate from the swelling and melting of the fuel.

——	December 8, 1st day.	December 9, 2nd day.
Fire lighted	9 hrs.	10 hrs.
Steam up	9h. 50m.	10h. 25m.
Weight of Wood used	10 lbs.	10 lbs.
Initial Temperature of Water in Boiler	198°	204°
Temperature of Water in Tanks	48°	50°
Barometer	..	29·86 in.
Extremes of external Thermometer	32°—56°	49°—56°
Extremes of internal Thermometer	48°—56°	60°—67°

—	December 8, 1st day.	December 9 2nd day.
Dew-point	40°	54°
Area of Damper open	112 in.	84 in.
Weight of Coals consumed	584 lbs.	446 lbs.
Weight of Ashes left	10 lbs.	8 lbs.
Per centage of combustible matter in Ashes	40·2	18·2
Weight of Cinder left	6 lbs.	5 lbs.
Per centage of combustible matter in Cinder	93·5	84·3
Weight of Clinker in Cinder	19 lbs.	16 lbs.
Average weight of Soot in flues	..	..
Per centage of combustible matter in Soot	..	..
Weight of Water evaporated	3660 lbs.	3740 lbs.
Weight of Water evaporated from 212° by 1 lb. of Coal	7·33 lbs.	9·74 lbs.
Weight of Coals per hour for 1 square foot of grate surface	14·6 lbs.	15·15 lbs.
Duration of Experiment	8 hrs.	8 hrs.
Specific gravity of Coal	1·14	..
Mean weight of cubic foot of Coal	65·3 lbs.	..
Economic weight or space occupied by 1 ton	34·30 c. f.	..
Cohesive power of Coal	..	..

Note.—Final temperature on fourth morning 204°.

Summary.

—	Evaporating power, or number of pounds of Water evaporated from 212° by 1 lb. of Coal (economic).	Weight of 1 cubic foot of the Coal as used for fuel.—Lbs.	Weight of 1 cubic foot as calculated from the density.—Lbs.	Ratio of B. to C., or of the economical to the theoretical weight.	Difference per cent. between theoretical and economical weights.	Space occupied by 1 ton in cubic feet (economic weight).	Results of experiments on cohesive power of Coals (per centage of large Coals).	Evaporating power of the Coal, after deducting for the combustible matter in the residue.	Per centage of residue in Coal. —Mean.	Weight of Water evaporated from 212° by 1 cubic foot.
	A.	B.	C.	D.	E.	F.	G.	H.	I.	K.
Pontypool	7·47	55·7	82·35	·6763	47·845	40·216	57·5	8·04	12·63	416·07
Bedwas	9·79	50·5	82·6	·6113	63·565	44·32	54·0	9·99	4·79	494·39
Porthmawr	7·53	53·3	86·722	·614	62·7	42·02	62·0	7·75	9·54	401·34
Warlich's Patent Fuel	10·36	69·05	72·248	·955	4·49	32·44	..	10·60	6·79	715·35
Ebbw Vale	10·21	53·3	78·81	·676	45·98	42·26	45·0	7·10	5·87	544·19
Dalkeith Jewel Seam	7·08	49·8	79·672	·625	59·984	44·98	85·7	7·10	3·92	352·58
,, Coronation Seam	7·71	51·66	78·611	·657	52·17	43·36	88·2	7·86	5·9	398·29
Fordel Splint	7·56	55·0	78·611	·699	42·92	40·72	63·	7·69	2·86	415·80
Wallsend Elgin	8·46	54·6	78·611	·694	43·78	41·02	64·	8·67	4·73	460·82
Slievaradagh	9·85	62·8	99·57	·630	58·55	35·66	74·	10·49	7·25	618·58
Coleshill	8·0	53·0	80·483	·658	51·85	42·26	62·	8·34	7·78	424·00
Bell's Patent Fuel	8·53	65·3	71·124	·918	8·91	34·30	..	8·65	6·70	577·00

Comparison between the Effects produced by the Boilers at Par Consols Mine and those obtained from that employed for the purposes of the foregoing Investigation.

A large amount of facts relative to the evaporative powers of various coals having been amassed during the progress of this inquiry, it was thought desirable to ascertain how nearly these results approach the maximum duty

obtained from Cornish boilers, and thus furnish a means of comparison between the apparatus employed for the purposes of this investigation and larger boilers of similar construction, as used for practical purposes.

Experiments have at different times been made, in order to ascertain with accuracy the quantity of water which can, under the most favourable circumstances, be evaporated from a given temperature by the combustion of one pound of coal.

No very decisive results appear, however, to have been arrived at; as, on consulting those of the different experimentalists, considerable differences will be observed. Smeaton, who seems to have been the first to pay serious attention to this subject, found, in the year 1772, that one pound of Newcastle coal evaporated 7·88 lbs. of water from 212°. Watt, who turned his attention to this subject in the year 1788, arrived at the conclusion that 8·62 lbs. of water might be evaporated from the temperature of 212° by one pound of the coal employed in his experiments; whilst Mr. Wicksteed, in the year 1840, found that one pound of Merthyr coal could be made to evaporate 9·493 lbs. of water from the temperature of 80° Faht., which is equal to the evaporation of 10·746 lbs. from the temperature of 212°.

Some experiments were also made about this time on the boilers of Loam's engine, at the United Mines, in Cornwall, to which was adapted an apparatus which correctly measured the quantity of water injected into the boilers. The experiment was continued six months, and, during that time, it was found that 234,210 cubic feet of water, at the temperature of 102° Faht., had been pumped into the boiler, and that 700 tons of coal had been consumed in its evaporation; thus showing that 15 cubic feet of water, at 102°, had been evaporated for each 100 lbs. of coals used, or that each pound of coals consumed had evaporated 10·29 lbs. of water from the temperature of 212° Faht.

It will be observed that these results not only differ considerably from each other, but also that no means was employed for the purpose of ascertaining the chemical composition of the various coals used, which should, we conceive, form an important part of all such investigations. In order, therefore, to obviate this inconvenience, as well as to take advantage of such improvements as may have been introduced since the dates of the foregoing experiments, it was determined to make a similar inquiry into the evaporating powers of the boilers of one of the best Cornish engines of the present day. That chosen for this purpose was the large pumping engine at Par Consols Mine, where every facility was afforded by Mr. West, the engineer, for carrying on the experiments effectually. This engine is an 80, with a 12-foot stroke in the cylinder, and is worked by two boilers,* to which is added an arrangement by which the feed-water is heated to near the boiling point before entering the boiler. This is effected by means of the waste heat, escaping from the flues; and the apparatus consists of two wrought-iron tubes, each

* The boilers on which this experiment was made are each 32 ft. in length and 6 ft. 3 in. in diameter. Each boiler presents a heating surface of 950 sq. ft., and the warming apparatus offers a surface of 560 sq. ft. to the action of the heated gases.

about 20 inches in diameter, placed above each other, and parallel to the axis of the boilers, in the brickwork of which they are inclosed. The feed-water is pumped into the upper tube by means of the usual arrangement, and then descends through a pipe into the lower one, from whence it passes into the boiler itself. Both these tubes are exposed in their whole length to the action of the heated gases coming from the fires, which, after having made the circuit of the boilers, pass round the warming tubes before arriving at the base of the chimney; the water in the tubes is thus heated to about 212° by means of the heat absorbed from the gases passing through the flues, and of which the temperature is reduced to about 300° by the time they arrive at the base of the chimney. Our experiments were conducted in the following manner:—

It was first necessary to be enabled to measure with accuracy the quantity of water supplied to the boilers; and in order to effect this, a large cistern was placed near the air-pump, from the cistern of which it could, by a simple arrangement, be filled with water. The connecting pipe between the feed-pump and air-pump cistern was then removed, and a pipe fitted to the feed-pump, which reached the bottom of the reservoir. The cistern was also provided with a waste-pipe, which prevented its being filled beyond a certain point; it was then filled with water and pumped out, in order to ascertain at what level the pump ceased to act. This point being decided, water was weighed into the cistern until it reached the level of the waste-pipe before mentioned, when it was found to contain 1260 lbs. It was also necessary to be enabled to stop the action of the feed-pump during the filling up of the cistern; and this was accomplished by means of a stop-cock placed in the feed-pump immediately under the stuffing-box, which, when opened, let in air and prevented the formation of a vacuum.

The measurement of the injected water was thus rendered excessively easy, as it was only necessary to count the number of cisterns pumped into the boilers, and open the stop-cock whilst it was being filled in order to do so with accuracy.

The arrangements for measuring the water having been completed, the experiment was begun; and at the expiration of 46½ hours it was found that 95 cisterns of water* had passed into the boiler, and that 11,730 lbs. of coals had been consumed; or, in other words, that 11,730 lbs. of coals had been consumed in order to evaporate 119,700 lbs. of water from the temperature of 92° Faht., which gives 10·204 lbs. of water evaporated from that temperature for every pound of coal consumed. If, as in the former part of this Report, we take 212° as the standard temperature, we find that each pound of coal employed had evaporated 11·428 lbs. of water from the boiling point.

The combustible employed during this experiment consisted of a mixture of Swansea and Bury coal; but in what proportion, or from what pits, we

* We took care to assure ourselves, by means of the gauges, that the boiler contained the same quantity of water at the beginning and close of the experiments.

were unable to learn. An analysis of the mixture was, however, made by my colleague, Mr. H. How, who obtained the following results:—

Carbon	84·19
Hydrogen	4·19
Oxygen	0·86
Nitrogen	0·80
Ash	8·06
Sulphur	1·90
Total	100·0

These coals were also found to contain 6 per cent. of water, the greater portion of which had been intentionally added, for the purpose of communicating intensity to the heat obtained during their combustion.

Having now ascertained the quantity of water evaporated by one pound of coals, as well as the composition of the coal employed, it remains to institute a comparison between the evaporative capacity of the boilers experimented on, and that employed for the purposes of this inquiry. In order to have done this, it would have been desirable to have made a comparative experiment with the same coal when consumed in the latter boiler; but as circumstances prevented this from being done, we may obtain nearly the same results by consulting the table of analyses, and selecting a coal having as nearly as possible the same composition as that in question. If we compare the following analyses, it will be found that the Mynydd Newydd coals are so similar in their composition to those used in the Cornish experiment, as to be considered practically identical:—

Analyses.

	Mynydd Newydd.	Cornish.
Carbon	84·26	84·19
Hydrogen	5·61	4·19
Ash	3·26	8·06
Sulphur	1·21	1·90
Nitrogen	1·56	0·80
Oxygen	3·52	0·86
Total	100·00	100·00

The practical trial made on the Mynydd Newydd coal in the experimental boiler, gave 9·52 as its evaporative value; if, then, we assume that the two coals possess equal calorific powers, the evaporative values of the two boilers will evidently be as 9·52 is to 11·42; or, in other words, the Cornish boilers will be found to possess a superiority of nearly 20 per cent. over that used for the purposes of the investigation.

Assuming, then, the economic equality of these two coals, we have only to multiply the results obtained by the various coals during our own experiments by 1·1995, in order to ascertain their several evaporative values if consumed under the Cornish boilers.

The following Table has been calculated upon this assumption*, and should therefore be considered only as an approximation:—

TABLE X.

Name of Coal.	Evaporative Power, Admiralty boiler. Actual.	Evaporative Power, Cornish boiler. Theoretical.
Mynydd Newydd	9·52	11·42
Graigola	9·35	11·21
Anthracite (Jones and Aubrey)	9·46	11·34
Old Castle Fiery Vein	8·94	10·72
Ward's Fiery Vein	9·40	11·27
Binea	9·94	11·92
Llangenneck	8·86	10·62
Pentrepoth	8·72	10·46
Pentrefelen	6·36	7·62
Powell's Duffryn	10·149	12·17
Three-quarter Rock Vein	8·84	10·60
Cwm Frood Rock Vein	8·70	10·43
Cwm Nanty-Gros	8·42	10·10
Resolven	9·53	11·43
Pontypool	7·47	8·96
Bedwas	9·79	11·74
Ebbw Vale	10·21	12·24
Porthmawr	7·53	9·03
Dalkeith Jewel Seam	7·08	8·49
,, Coronation Seam	7·71	9·24
Wallsend Elgin	8·46	10·14
Fordel Splint	7·56	9·06
Grangemouth	7·40	8·87
Coleshill	8·00	9·59
Broomhill	7·30	8·75
Lydney	8·52	10·22
Slievardagh (Irish)	9·85	11·81
Wylam's Patent Fuel	8·92	11·70
Warlich's ,,	10·36	12·42
Bell's ,,	8·53	10·23

Experiment for determining the Coefficient of the Evaporative Power of Wood, and the Formulæ used in calculating the results. By Mr. J. ARTHUR PHILLIPS.

IN the formulæ for calculating the evaporative power of wood and coal, as given in the preceding chapter, no notice is taken of the expansion and contraction of the water in the boiler from an increase or diminution of temperature; and, therefore, although sufficiently exact for practical purposes, they are not strictly correct.

In order to make this allowance, it will be necessary to ascertain what

* The Mynydd Newydd coal, supposing there was no loss of heat, is capable of evaporating 14·90 lbs. of water, and the Welsh coal (used in Cornwall) 14·28 lbs.; but considering that this heat cannot all be obtained in practice, these economic values for calculation might be taken as equal without introducing any serious error.

weight of water the boiler contains, when filled to the normal point, at the various temperatures within the extremes of observed difference.

With this view, the boiler was filled to the normal point with water at the temperature of 70° Fahrenheit, when it was found to contain 4730 lbs.; the fire was then lighted, and the increase of heat noted by means of a thermometer, placed in the tube L, containing mercury; the water was soon observed to expand and rise slowly above the normal point, and at each successive elevation of 20° marked by the thermometer, the excess of water was drawn off down to the normal point, by means of the cock R″, and weighed; these successive weighings furnished the data from which the following Table has been calculated.

TABLE showing the Expansion of Water in the Boiler at different Temperatures.

Temperature of Water, Fahrenheit.	Ratio of apparent to real Weight.	Actual Weight of Water in Boiler when filled to Normal Point.	Difference between actual and apparent Weight.
°		Lbs.	
70	1·0000	4730·000	0·000
80	0·9996	4728·108	1·892
90	0·9292	4726·216	3 784
100	0·9987	4723·950	6·050
110	0·9983	4721·960	8·040
120	0.9979	4719·097	10·903
130	0·9974	4717·795	12·205
140	0·9971	4715·283	14·717
150	0·9967	4714·012	15·988
160	0·9954	4708·242	21·758
170	0·9940	4701·620	28·388
180	0·9923	4693·579	36·421
190	0·9901	4683·173	46·827
200	0·9879	4672·767	57·933
202	0·9869	4668·037	61·963
204	0·9859	4663·307	66·693
206	0·9849	4658·577	71·423
208	0.9839	4653·847	76·153
210	0·9829	4649·117	80·883
212	0·0819	4644·387	85·613

Between the temperatures of 150° and 212° a variation of 69·625 lbs. in the weight of water contained in the boiler will be observed, which, though an extreme case, clearly shows that, even when a difference of 10° has been observed between the initial and final temperatures, allowance should be made for it in the calculations.

It was also thought advisable to ascertain with great accuracy the evaporative power of the wood used in lighting the fires; for this being a constant in all the experiments, it is obviously of great importance.

Determination of the heating powers of wood; method of correction for the wood used in lighting the fire.

In order to ascertain the evaporative power of wood when applied to this particular boiler, it was filled to the normal point with water at the tempera-

ture of 212° Fahrenheit; the fire was then supplied with wood during eight consecutive hours, at the expiration of which time it was allowed to burn slowly out, and on the following morning water was let down from the tanks, till it again attained the normal level marked on the water-gauge of the boiler, when it was found that the mixture had a temperature of 200° Fahrenheit. It was also ascertained that from the commencement of the experiment 1800 lbs. of water had been let down from the tank, and that 639 lbs. of wood had been consumed.

From these data, then, we have to find the coefficient required; and this may be done in the following manner:—

A. On consulting the table which has been constructed for this purpose, we find that the boiler contains more water, by 28·380 lbs., at the close of the experiment than it did at its commencement; in order, therefore, to ascertain the quantity actually evaporated from that let down into the boiler during the experiment, we have 1800 — 28·380 = 1771·62 lbs., which is the actual weight of water which has been evaporated.

But as in this experiment the water is supposed to be evaporated from 212°, we have other considerations to attend to, and the second is, the allowance to be made for the quantity of heat necessary to raise 1771·62 lbs. of water from 70°, the mean temperature of the tanks, to the temperature of ebullition; we therefore multiply 1771·62 by 142·88, which is the quantity of heat expressed in degrees of Fahrenheit necessary to raise the former to the latter temperature,* and the result, 253,129, shows how many pounds of water at 0° would be raised 1° in temperature by the same quantity of caloric. We have, therefore, only to divide this sum by 965·7, the coefficient of the latent heat of steam at the temperature of 212°, to find its equivalent value in water evaporated from that temperature; this we find to be 262·12, which should be added to 1771·62, found in section A. Thus we have 1771·62 + 262·12 = 2033·74 lbs.

C. Another cause of error to be considered and allowed, is that which arises from the difference in the temperature of the water in the boiler at the beginning and close of the experiment.

In the present case, the water, when the experiment was completed, was 12° colder than at its commencement. And thus we have to subtract from the water evaporated at 212° a quantity equivalent to the heat which would be required to raise the same weight of water as that contained in the boiler at the commencement of the experiment, from the final to the initial temperature. We have, therefore, to seek, in the table already alluded to, the weight of water corresponding to the initial temperature; which, in the present instance, we find to be 4644·387, which, being multiplied by 12·1308, and divided by 965·7, gives 58·340, the weight of water which, if evaporated from 212°, would be equivalent to raising 4644·387 lbs. of water from 0° to 12°, and this should evidently be subtracted from 1771·62 + 262·12 = 2033·73 lbs., resulting from the preceding operations. We have, then, 2033·73 — 58·340 = 1975·400 lbs.

D. There now remains to be made a slight correction for 28·380 lbs. of

* It will be found from Table II., that the mean specific heat of water between 70° and 212° is 1·0062.

water subtracted in the first operation, for this weight has evidently been raised from 70° to 200°, and for which allowance must be made.

We find, by the usual formulæ, the value of this to be 3·617 lbs., which must be added to 1975·400 already found. We have, then, 1975·400 + 3·617 = 1979·017 lbs., which, divided by the weight of wood employed, will give the coefficient of its evaporative power, which we find to be 3·097.*

These operations can be conveniently expressed by the following formulæ:—

$$\frac{(W + w - w')\,(l + t) + wt' + (w' - w)\,t''}{P\,l} = E$$

In which W represents the total quantity of water let down from the tanks into the boiler during the experiment.

w = The weight of water (as found in the table) contained in the boiler at the commencement of the experiment.

w' = The weight of water contained in the boiler at the close of the experiment.

l = Coefficient of the latent heat of steam.

t = Quantity of heat (expressed in degrees of Fahrenheit) necessary to raise the water in the tanks from its mean temperature to that at which it has been evaporated.

t' = The quantity of heat necessary to raise the initial to the final temperature of the water in the boiler.

t'' = Quantity of heat necessary to raise water at the temperature of the tanks to the final temperature of the water in the boiler.

P = Weight of combustible consumed during the experiment.

E = The coefficient of the heating power of wood. It is here to be remarked that, when the initial is lower than the final temperature, the formula becomes—

$$\frac{(W + w - w')\,l + W\,t + wt' + (w' - w)\,t'''}{P\,l} = E$$

In which each term retains its original value, except the last, in which t'' is replaced by t''', which is the quantity of heat necessary to raise the final temperature to the temperature at which the water was evaporated; and must be regarded as having a negative value, whilst t' becomes positive.

If, then, we call q the weight of wood employed in lighting the fire, the formulæ for estimating the evaporative power of coals will be—

$$\frac{(W - E\,q + w - w')\,l + (W + w - w')\,t + wt' + (w' - w)\,t''}{P\,l} = E$$

* A similar experiment, during which 1056 lbs. of wood was consumed, gave the number 3·036. These results are much lower than those obtained by other experimentalists; but this difference probably arises from the smallness and dampness of the wood employed, added to the great loss of heat occasioned by the very quick draught necessary to carry off the smoke evolved. The frequent opening of the fire-doors for the purpose of charging must also have contributed to the same effect.

and

$$\frac{(W - E\,q + w - w')\,l + W\,t + wt' + (w' - w)\,t'''}{P\,l} = E$$

It might perhaps appear that an allowance be made in these formulæ for the heat absorbed by the apparatus employed for the purpose of equalizing the temperature of the water in the boiler, as it is evident that the tubes Q Q Q, &c., must become heated during the process of pumping the water from the bottom of the boiler, in order to distribute it on the surface; but, by the following considerations, it becomes evident that this quantity is so extremely small as to be safely neglected in the calculations.

Firstly,—The pumping of the water is always finished previously to establishing the normal level by letting down the water from the tanks; therefore the whole, or by far the greater portion, of the heat absorbed by the apparatus is again yielded to the cold water, as it passes through them. It is also evident that the value of this difference may be easily calculated from the following data. The apparatus is formed of 300 lbs. of iron and 35·5 lbs. of copper; if, then, we take the specific heat of iron at 0·11379, and that of copper at 0·09515, we find that the calorific value of the whole apparatus will be equal to 37·514 lbs. of water.

It was shown, by a mean of three experiments, that the cold water let down into the boiler had absorbed from the apparatus 2° of heat more than had been communicated to it during the process of pumping; and as the value of this difference on the coefficient of the evaporative power of a combustible will be of the form $\frac{\pi\,\theta}{Pl}$*, we find that for an ordinary operation in which 350 lbs. of fuel have been consumed, and 3500 lbs. of water evaporated, this difference will influence the result in the proportion of 10·0000 to 10·0002, which is infinitely too small to merit attention in a practical investigation like the present.

The latent heat of steam between the temperature of 32° and 446 Fahrenheit, as well as the mean specific heat of water between 32° and T, and the specific heat of the same fluid from T to T + d T, will be found in the following table, extracted from "Regnault's Mémoire," published in the "Transactions de l'Institut de France," tome xxi.

These numbers were employed in all the calculations from the foregoing formulæ, and corrections have constantly been made for the expansion and contraction of the water in the tanks, as well as of the tanks themselves, whenever the temperature has varied 2° from that at which the water gauges were graduated.

These corrections were made by means of the Table No. II., calculated from the known expansion and contraction of water between the temperatures of 43° and 80° Fahrenheit, and the cubic contraction of wrought-iron vessels between the same temperatures.

* π = Calorific value of the apparatus. θ = Difference of temperatures. P = weight of combustible employed. l = Latent heat of steam.

TABLE No. II.

CORRECTION for EXPANSION and CONTRACTION of WATER in the TANKS, taking 70° as the Normal Temperature.

Temperature, Fahrenheit.	Actual Weight of an Unity of Water.	Temperature, Fahrenheit.	Actual Weight of an Unity of Water.
° 40	1·001464	° 62	1·000712
42	1·001451	64	1·000534
44	1·001439	66	1·000356
46	1·001426	68	1·000178
48	1·001414	70	1·000000
50	1·001401	72	·999763
52	1·001294	74	·999527
54	1·001196	76	·999290
56	1·001094	78	·999054
58	1·000992	80	·998818
60	1·000890		

SECTION III., PART I.—*Chemical Analyses of Coals.* By MR. F. C. WRIGHTSON.

In the analyses of the coals, great care was taken to have a fair average, by breaking up a large quantity of the coal, and from that selecting a smaller specimen for examination.

As a control experiment, and to see how far the average differed from the best sample, a portion of pure coal was selected, and also analysed.

Hygrometric Water was determined by drying the coal in a water bath, and ascertaining the loss.

Carbon and Hydrogen.—More accurate results were obtained by operating upon three or four grains than upon a larger quantity. The coal was reduced to an impalpable powder, dried and mixed in a combustion tube with dry chromate of lead, by means of a screw wire. The combustion was made in the ordinary way.

Nitrogen was determined by the usual plan, known to chemists as "Will and Varrentrapp's method."

Sulphur was determined by mixing the coal with twice its weight of pure precipitated carbonate of lime, placing the mixture in a tube blown into a bulb in the middle, and burning it in a stream of oxygen gas with the aid of a spirit lamp. When completely burnt (which is readily perceived by the whiteness of the mass, and its solubility in hydrochloric acid), the whole is thrown upon a filter, the sulphate of lime washed out, and the sulphuric acid precipitated by chloride of barium, and estimated as sulphate of barytes. From this amount the quantity of sulphuric acid existing in the ashes of the coal is subtracted.

Ashes were determined by burning 15 or 20 grains of the coal in a platinum capsule over a spirit lamp, or by doing the same in a tube of green glass in a stream of oxygen gas.

Oxygen was ascertained by loss on the analysis.

The proximate analyses of the coals were performed by the process described by Professor Bunsen and Dr. Playfair, in the Reports of the British Association, vol. xiv., p. 142.

ULTIMATE ANALYSES.

Graigola Coal.

This coal contained 1·06 per cent water: dried at 212° Fah.

Average Coal.

0·2290	gramme, gave	0·078	carbonic acid, and	0·0732 water.
0·4170	,,	1·3065	,,	0·1558 ,,
0·8633	,,	0·0573	platinum salt of ammonia.	
2·3980	,,	0·1100	sulphate of baryta.	
0·5086	,,	0·0170	ash.	
0·5165	,,	0·0180	,,	

Anthracite, from T. Aubrey and Co.

This gave 2·44 per cent. water: dried at 212° Fah.

Average Coal.

0·2763	gramme, yielded	0·9310	carbonic acid, and	0·0863 water.
0·2923	,,	0·9827	,,	0·0920 ,,
0·9234	,,	0·0313	platinum salt.	
2·0799	,,	0·1248	sulphate of baryta.	
0·7097	,,	0·0110	ash.	
0·7645	,,	0·0115	,,	

Oldcastle Fiery Vein Coal.

This coal contained 7·40 per cent. water: dried at 212°.

Average Coal.

0·4430	gramme, gave	1·4247	carbonic acid, and	0·1945 water.
0·4995	,,	1·5860	,,	0·2186 ,,
0·8990	,,	0·1405	platinum salt.	
2·172	,,	0·215	sulphate of baryta.	
0·6755	,,	0·0175	ash.	
0·7120	,,	0·0192	,,	
Pure Coal.				
0·3055	,,	0·9945	carbonic acid, and	0·1365 water.
0·4200	,,	0·1100	platinum salt.	

Ward's Fiery Vein.

This coal contained 1·37 per cent. water: dried at 212°.

Average Coal.

5·103	grs. gave	16·44	carbonic acid, and	1·805 water.
11·675	,,	1·895	platinum salt.	
12·585	,,	0·765	sulphate of baryta.	
8·805	,,	0·630	ash.	
15·075	,,	1·050	,,	

Note.—The pure coal contained only 3·82 per cent. ash.

Binea.

This coal contained between 0·82 and 0·91 per cent. water: dried at 212°.

Average Coal.

4·255 grs.	gave	13·845 carbonic acid, and	1·737 water.
3·255	,,	10·525 ,,	1,344 ,,
10·110	,,	2·350 platinum salt.	
15·605	,,	0·380 sulphate of baryta.	
17·265	,,	0·690 ash.	
9·095	,,	0·358 ,,	

Pure Coal.

3·955	,,	12·917 carbonic acid, and	1·710 water.
15·975	,,	0·380 ash.	

Llangenneck.

Hygrometric water was not determined: of the dry coal—

Average Coal.

4·079 grs.	gave	12·860 carbonic acid, and	1·682 water.
4·145	,,	13·060 ,,	1·540 ,,
8·380	,,	1·425 platinum salt.	
8·620	,,	0·185 sulphate of baryta.	
7·293	,,	0·434 ash.	
5·719	,,	0·370 ,,	

Pure Coal.

3·585	,,	11·060 carbonic acid, and	1·325 water.

Pentrepoth.

Hygrometric water not determined: when dried—

Average Coal.

3·135 grs.	gave	10·188 carbonic acid, and	1·225 water.
3·128	,,	10·155 ,,	1·315 ,,
10·040	,,	0·310 platinum salt.	
6·490	,,	0·215 ash.	
9·50	,,	0·325 ,,	

Sulphur not estimated.

Dalkeith Jewel Seam.

This coal gave 9·3 per cent. water: dried at 212°.

Average Coal.

2·935 grs.	gave	7·970 carbonic acid, and	1·379 water.
2·854	,,	7·855 ,,	1·303 ,,
12·073	,,	0·200 platinum salt.	
6·275	,,	0·155 sulphate of baryta.	
4·290	,,	0·190 ash.	
8·315	,,	0·360 ,,	

Pure Coal.

2·680	,,	8·260 carbonic acid, and	1·381 water.
11·892	,,	0·085 ash.	

Dalkeith Coronation Seam.

This coal contained 5·88 per cent. water: dried at 212°.

Average Coal.

2·761 grs.	gave	7·800 carbonic acid, and	1·927 water.
2·647	,,	7·425 ,,	1·258 ,,
6·125	,,	0·280 sulphate of baryta.	
7·362	,,	0·224 ash.	
8·035	,,	0·300 ,,	

Nitrogen in too small amount to estimate.

Pure Coal.

3·743 grs.	gave	10·605 carbonic acid, and	1·722 water.
11·913	,,	0·355 ash.	

Pentrefelan.

Hygrometric water not determined: when dried at 212°.

Average Coal.

4·025 grs.	gave	12·950 carbonic acid, and	1·355 water.
4·008	,,	12·250 ,,	1·410 ,,
5·445	,,	0·495 sulphate of baryta.	
9·075	,,	0·550 ash.	
19·153	,,	1·175 ,,	

Pure Coal.

2·573	,,	8·065 carbonic acid, and 0·815 water.
7·870	,,	0·305 ash.

In the following Tables are given—firstly, the per-centage results for the average composition of the coals, calculated from the above numbers; secondly, the per-centage results of the experiments on pure coal.

Name of Locality of Coal.	Carbon.		Hydrogen.		Ash.		Sulphur.	Nitrogen.
	I.	II.	I.	II.	I.	II.		
Graigola	84·31	85·44	3·54	4·15	3·14	3·34	0·45	0·41
Anthracite (Aubrey and Co.)	91·19	91·69	3·44	3·49	1·55	1·50	0·79	0·21
Oldcastle Fiery Vein . .	87·70	86·59	4·87	4·86	2·59	2·69	0·09	0·99
Ward's Fiery Vein . . .	87·87	..	3·93	..	7·04	..	0·83	1·02
Binea	88·73	88·18	4·53	4·58	3·93	3·99	0·33	1·43
Llangenneck	85·98	85·93	4·58	4·12	6·91	6·17	0·29	1·07
Pentrepoth	88·62	88·83	4·34	4·67	3·31	3·41	..	0·18
Dalkeith Jewel Seam . .	74·05	75·06	5·21	5·07	4·32	4·42	0·33	0·10
,, Coronation Seam .	77·04	76·50	5·21	5·28	3·35	3·38	0·38	trace
Pentrefelan	87·74	83·35	3·74	3·90	6·06	6·13	0·12	trace

Per-centage results of experiments on pure coals:—

Name of Locality.	Carbon.	Hydrogen.	Ash.	Nitrogen.
Oldcastle Fiery Vein . . .	88·75	4·96	..	1·64
Binea	89·07	4·80	2·38	..
Llangenneck	84·46	4·10	..	..
Dalkeith Jewel Seam . . .	78·76	5·36	0·71	..
,, Coronation Seam .	77·29	5·11	2·97	..
Pentrefelan	85·48	3·52	3·87	..

PROXIMATE ANALYSES.

Graigola Coal.

	Grains.	Per-centage Results.
Coal used	337·565	
Coke obtained . . .	288·390	85·5
Tar ,, . . .	4·200	1·2
Water ,, . . .	10·768	3·1
Carbonic acid obtained	9·440	2·79
Sulphuretted Hydrogen obtained	trace.	trace.
Olefiant gas obtained .	0·785	0·23
Ammonia ,, .	0·592	0·17
	Other gases .	7·01
		100·00

Note.—The coke obtained in this analysis lost by prolonged heating, in two trials, 5·6 per cent. and 6·7 per cent.

ANTHRACITE, from AUBREY and SON.

	Grains.		Per-centage.
Coal employed	326·000		
Coke obtained	303·090		92·9
Tar ,, . . .	none.		none.
Water ,, . . .	9·365		2·87
Platinum salt obtained .	8·580	Ammonia	0·20
Sulphuret of lead ,, .	0·940	Sulphuretted hydrogen .	0·04
Carbonic acid ,, .	0·212	Carbonic acid . . .	0·06
Olefiant gas ,, .	?	Other inflammable gases	3·93
			100·00

OLDCASTLE FIERY VEIN.

	Grains.		Per-centage.
Coal employed	106·250		
Coke obtained	84·75		79·80
Tar ,, . . .	6·230		5·86
Water ,, . . .	3·611		3·39
Platinum salt obtained	4·832	Ammonia	0·35
Sulphuret of lead ,,	0·915	Sulphuretted hydrogen .	0·12
Carbonic acid ,,	0·470	Carbonic acid. . . .	0·44
Olefiant gas ,,	0·290	Olefiant gas and hydro-carbon	0·27
		Other inflammable gases	9·77
			100·00

WARD'S FIERY VEIN.

	Grains.		Per centage.
Coal employed	236·910		
Coke	lost by accident.		
Tar obtained	4·270		1·80
Water ,, ...	7·150		3·01
Platinum salt obtained .	7·650	Ammonia	0·24
Sulphuret of lead ,,	3·970	Sulphuretted hydrogen .	0·21
Carbonic acid ,,	4·280		1·80
Olefiant gas ,,	0·500		0·21

BINEA COLS.

	Grains.		Per-centage.
Coal employed	313·860		
Coke obtained	276·170		88·10
Tar ,, . . .	6·540		2·08
Water* ,, . . .	14·540		3·58
Carbonic acid obtained .	5·296		1·68
Olefiant gas and hydro-carbon	0·985		0·31
Platinum salt . . .	3·540	Ammonia	0·08
Sulphuret of lead. . .	2·070	Sulphuretted hydrogen .	0·09
		Other gases	4·08
			100·00

* In the proximate analyses, the coal was not dried previous to its being heated; and, therefore, the water is in greater quantity than corresponds to the oxygen found.

LLANGENNECK.

	Grains.		Per-centage.
Coal employed . . .	311·730		
Coke obtained . . .	260·890		83·69
Tar ,, . . .	3·795		1·22
Water ,, . . .	12·701		4·07
Carbonic acid obtained .	10·023		3·21
Olefiant gas ,, .	1·340		0·43
Platinum salt ,, .	3·280	Ammonia	0·08
Sulphuret of lead ,, .	0·610	Sulphuretted hydrogen .	0·02
		Other gases	7·28
			100·00

SECTION III., PART II.—*Chemical Analyses of the Coals.* By Mr. H. HOW.

ULTIMATE ANALYSES OF COALS.

THE methods pursued for the estimation of the constituents of the coals in the following analyses were precisely identical with those already specified, with the exception of that for the determination of the sulphur. The amount of this element was ascertained by fusing about 10 grains with carbonate of soda and nitre in proper proportions, and then proceeding in the usual way for estimating sulphuric acid: this method was preferred as occupying far less time than the one before mentioned.

With regard to analyses of "pure coal," it was thought unnecessary to multiply instances of this kind, a sufficient number being already brought forward to show generally the nature of different parts of a coal, and a knowledge of this variation in every instance would not possess a practical utility great enough to justify the occupation of the considerable time requisite for the extension of the investigation in this particular direction; while the fact of my being aware of the existence of such a want of uniformity has made me most careful to obtain such an average sample of each coal as shall express most fairly upon analyses the real value of the mass; the following are the results:—

EXPERIMENTAL NUMBERS IN THE ANALYSES.

POWELL'S DUFFRYN COAL.

This coal contained 1·13 per cent. of water: dried at 212°.

Coal.		
2·15 grs.	yielded	6·97 carbonic acid and 0·88 water.
2·03	,,	6·56 ,, ,,
11·31	,,	0·36 ash.
10·78	,,	0·36 ,,
8·73	,,	2·02 chloride of platinum and ammonium.
6·93	,,	0·926 sulphate of baryta.

Mynydd Newydd.

This coal yielded 0·61 per cent. of water: dried at 212° Fah.

Coal.			
3·56	grs. gave	11·00 carbonic acid	and 1·80 water.
3·49	,,	10·90 ,,	and 1·86 ,,
12·20	,,	0·40 ash.	
4·35	,,	0·14 ,,	
10·00	,,	2·52 bichloride of platinum and ammonium.	
6·63	,,	0·615 sulphate of baryta.	

Coal swells up much on heating, burns with much flame, and leaves a bright red ash.

Three-quarter Rock Vein.

This coal yielded 1·67 per cent. of water: dried at 212° Fah.

Coal.			
3·65	grs. gave	10·10 carbonic acid	and 1·65 water.
3·96	,,	10·87 ,,	and 1·73 ,,
9·99	,,	1·07 ash.	
9·81	,,	1·10 ,,	
13·40	,,	2·36 bichloride of platinum and ammonium.	
8·33	,,	1·87 sulphate of baryta.	

Coals swells up much in burning; leaves a grey ash.

Park End Coals, Lydney.

This coal contained 2·78 per cent. of water: dried at 212° Fah.

Coal.			
3·15	grs. gave	8·47 carbonic acid	and 1·6 water.
2·63	,,	7·11 ,,	and 1·36 ,,
8·35	,,	0·83 ash.	
7·46	,,	0·75 ,,	
12·65	,,	4·15 platinum salt.	
8·13	,,	1·466 sulphate of baryta.	

Ash had a reddish colour.

Cwm Frood Rock Vein.

This coal gave 1·12 per cent. of water: dried at 212° Fah.

Coal.			
3·09	grs. yielded	9·26 carbonic acid	and 1·6 water.
3·37	,,	10·23 ,,	and 1·8 ,,
7·90	,,	0·47 ash.	
7·43	,,	0·45 ,,	
9·90	,,	1·76 platinum salt.	
10·42	,,	1·02 sulphate of baryta.	

Cwm Nanty-Gros.

This coal yielded 0·9 per cent. of water: dried at 212° Fah.

Coal.			
3·74	grs. gave	10·72 carbonic acid	and 1·93 water.
3·46	,,	9·97 ,,	and 1·70 ,,
6·60	,,	0·37 ash.	
6·23	,,	0·35 ,,	
7·72	,,	2·30 platinum salt.	
11·70	,,	2·665 sulphate baryta.	

Coal swells up much in burning, and leaves a red or pink ash.

Wylam's Patent Fuel.

This fuel contained 1·38 per cent. of water: dried at 212° Fah.

Fuel.			
3·46 grs.	gave	10·10 carbonic acid	and 1·7 water.
2·25	,,	6·62 ,,	and 1·17 ,,
7·33	,,	0·36 ash.	
5·64	,,	0·27 ,,	
10·47	,,	2·89 platinum salt of ammonia.	
8·17	,,	0·803 sulphate of baryta.	

Ash had a reddish-gray colour.

Grangemouth Coal.

This coal yielded 6·42 per cent. of water: dried at 212° Fah.

Coal.			
3·80 grs.	gave	11·16 carbonic acid	and 1·82 water.
3·75	,,	10·95 ,,	and 1·77 ,,
6·80	,,	0·24 ash.	
6·50	,,	3·23 ,,	
10·64	,,	2·30 platinum salt.	
7·73	,,	0·842 sulphate of baryta.	

Ash had a reddish-yellow colour.

Broomhill Coal.

This coal yielded 9·31 per cent. water: dried at 212° Fah.

Coal.			
3·035 grs.	gave	9·06 carbonic acid,	and 1·70 water.
2·85	,,	8·57 ,,	and 1·57 ,,
10·52	,,	0·33 ash.	
9·25	,,	0·28 ,,	
9·34	,,	2·71 platinum salt.	
7·01	,,	1·49 sulphate of baryta.	

Ash pale red.

Resolven.

This coal yielded 1·55 per cent. water: dried at 212° Fah.

Coal.			
3·85 grs.	gave	11·2 carbonic acid,	and 1·55 water.
3·53	,,		1·60 ,,
11·31	,,	1·07 ash.	
8·32	,,	0·78 ,,	
9·08	,,	2·07 platinum salt of ammonia.	
8·85	,,	3·39 sulphate of baryta.	

Ash was reddish brown.

Pontypool.

This coal yielded 1·6 per cent. water: dried at 212° Fah.

Coal.			
2·59 grs.	gave	7·65 carbonic acid,	and 1·29 water.
2·28	,,	6·76 ,,	and 1·19 ,,
8·57	,,	0·48 ash.	
13·19	,,	0·72 ,,	
7·41	,,	1·60 platinum salt.	
5·04	,,	0·895 sulphate of baryta.	

Bedwas.

This coal contained 1·28 per cent. water: dried at 212° Fah.

Coal.			
2·18	grs. gave	6·45 carbonic acid, and	1·16 water.
2·18	,,	6·44 ,, and	1·20 ,,
11·36	,,	0·80 ash.	
6·72	,,	0·46 ,,	
8·66	,,	1·98 platinum salt.	
4·82	,,	1·298 sulphate of baryta.	
5·48	,,	1·48 ,,	

Porthmawr Rock Vein.

This coal contained 1·7 per cent. water: dried at 212° Fah.

Coal.			
3·42	grs. gave	9·33 carbonic acid, and	1·47 water.
3·13	,,	8·61 ,, and	1·41 ,,
10·73	,,	1·59 ash.	
5·67	,,	0·83 ,,	
8·97	,,	1·88 platinum salt.	
7·36	,,	0·62 sulphate of baryta.	

Ash left was of a pearly white appearance.

Warlich's Patent Fuel.

This fuel yielded 0·92 per cent. water: dried at 212° Fah.

Fuel.			
3·49	grs. gave	11·49 carbonic acid, and	1·85 water
2·9	,,	9·60 ,, and	1·37 ,,
7·51	,,	0·22 ash.	
8·57	,,	0·25 ,,	
4·55	,,	0·566 sulphate of baryta.	

This fuel swelled a little on heating; left a red ash.

Bell's Patent Fuel.

Gave 0·9 per cent. water: dried at 212° Fah.

Fuel.			
3·84	grs. gave	12·33 carbonic acid, and	1·81 water.
3·96	,,	12·81 ,, and	1·86 ,,
5·63	,,	0·27 ash.	
7·60	,,	0·39 ,,	
13·53	,,	1·84 platinum salt.	
8·80	,,	0·517 sulphate of baryta.	

This fuel swells up very much, and leaves, on incineration, a gray ash.

Ebbw Vale Coal.

This coal contained 1·34 per cent. water: dried at 212° Fah.

Coal.			
3·10	grs. gave	10·15 carbonic acid, and	1·46 water.
3·19	,,	10·56 ,, and	1·46 ,,
13·73	,,	0·21 ash.	
8·14	,,	0·12 ,,	
8·12	,,	2·80 platinum salt of ammonia.	
7·48	,,	0·57 sulphate of baryta.	

Ash pale red.

Coleshill.

This coal contained 4·91 per cent. water: dried at 212° Fah.

Coal.			
3·99 grs.	gave	10·82 carbonic acid.	
3·82	,,	10·33 ,,	and 1·77 water.
5·01	,,	0·44 ash.	
11·36	,,	1·03 ,,	
12·76	,,	3·10 platinum salt.	
7·31	,,	1·34 sulphate of baryta.	

Coal burned without swelling, gave a great deal of smoke; ash left, on incineration, was grayish white.

Wallsend Elgin.

This coal contained 2·49 water per cent.: dried at 212° Fah.

Coal.			
3·96 grs.	gave	11·02 carbonic acid,	and 1·81 water.
4·26	,,	11·92 ,,	and 1·96 ,,
6·58	,,	0·70 ash.	
6·55	,,	0·71 ,,	
6·70	,,	0·852 sulphate of baryta.	
8·76	,,	1·97 platinum salt of ammonia.	

Coal burned without swelling at all, gave much smoke, left a yellowish-white ash.

Fordel Splint Coal.

This coal contained 8·4 per cent. water: dried at 212° Fah.

Coal.			
4·26 grs.	gave	12·41 carbonic acid,	and 2·11 water.
4·21	,,	12·31 ,,	
10·91	,,	0·42 ash.	
7·68	,,	0·32 ,,	
10·62	,,	1·96 platinum salt of ammonia.	
8·54	,,	0·95 sulphate of baryta	

Coal burned without swelling, gave much flame; left a white ash.

Slievardagh Coal. Anthracitic.

This coal contained 4·93 per cent. water: dried at 212° Fah.

Coal.			
3·53 grs.	gave	10·38 carbonic acid,	and 0·67 water.
3·54	,,	10·37 ,,	and 0·80 ,,
10·09	,,	1·10 ash.	
9·01	,,	0·97 ,,	
14·75	,,	0·56 platinum salt of ammonia.	
9·77	,,	4·968 sulphate of baryta.	

Coal burned without smoke or intumescence; left a red-brown ash.

The experimental numbers given above, when calculated upon in the usual manner for per-centage weights, lead to the results which are embodied in the following table:—

Table *showing the per-centage composition of the Coals analysed, as calculated from the numbers before given.*

Name or Locality of Coal.	Carbon.		Hydrogen.		Ash.		Sulphur.	Nitrogen.
	I.	II.	I.	II.	I.	II.		
Powell's Duffryn . . .	88·4	88·12	4·54	4·81	3·18	3·34	1·77	1·45
Mynydd Newydd. . .	84·26	85·16	5·61	5·92	3·27	3·21	1·21	1·56
Three-quarter Rock Vein	75·45	74·85	5·02	4·85	10·71	11·21	2·85	1·07
Park End, Lydney . .	73·32	73·72	5·64	5·74	9·95	10·05	2·27	2·04
Cwm Frood Rock Vein .	81·72	82·78	5·75	5·93	5·95	6·05	1·22	1·11
Cwm Nanty Gros . .	78·57	78·16	5·45	5·73	5·60	5·61	3·01	1·86
Grangemouth	80·09	79·62	5·32	5·24	3·52	3·53	1·42	1·35
Broomhill.	81·40	82·00	6·22	6·12	3·13	3·02	2·85	1·84
Wylam's Patent Fuel .	79·60	80·22	5·61	5·77	4·91	4·78	1·25	1·68
Resolven	79·33	lost.	4·47	5·03	9·46	9·37	5·07	1·38
Pontypool	80 85	80·54	5·79	5·53	5·60	5·45	2·39	1·35
Bedwas	80·68	80·55	5·91	6·11	7·04	6·84	3·70	1·44
Porthmawr Rock Vein .	74·39	75·01	4·58	5·00	14·81	14·63	0·91	1·28
Warlich's Patent Fuel .	90·26	89·78	5·24	5·88	2·92	2·90	1·63	trace.
Bell's Patent Fuel . .	87·56	88·21	5·23	5·21	4·79	5·13	0·71	0·81
Ebbw Vale	89·28	90·27	5·08	5·23	1·53	1·47	1·02	2·16
Wallsend Elgin . . .	75·83	76·30	5·33	5·11	10·63	10·78	1·53	1·41
Maxwell's Coleshill . .	73·95	73·74	5·14	lost.	8·78	9·06	2·34	1·47
Fordel Splint	79·44	79·73	5·50	lost.	3·84	4·16	1·46	1·13
Slievardagh	80·18	79·88	2·10	2·50	10·90	10·71	6·76	0·23

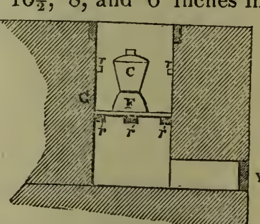
The mean results and the amount of oxygen per cent., as well as the quantity of oxygen required to consume the combustible ingredients of the coals, are given in the body of the Report.

Section IV., Part II.—*Calorific Values of the Coals.* By Mr. J. Arthur Phillips.

LITHARGE EXPERIMENTS.

In order further to test the calorific properties of the coals experimented on, as well as to compare their theoretic and economical values, a series of experiments was made relative to the quantity of litharge reduced by a given weight of each coal.

For this purpose we employed the furnace E, plates 1 and 2, which contains three distinct apertures, *s s s*, respectively $10\frac{1}{2}$, 8, and 6 inches in diameter; and in which a grating for the support of charcoal can be placed, either at the depth of 6 or 12 inches from the surface, by means of iron pegs, according to the degree of heat required.



This arrangement will be probably better understood by reference to the annexed wood-cut, in which *r r* and *r′ r′ r′* represent the iron pegs; Y the sliding door for regulating the draught, and G the grating. The crucible C, containing the mixture of litharge and pulverized coal, is placed on the support F.

This method of testing the calorific effects of a combustible is founded on the assumption, now pretty generally admitted, that its value is in direct ratio with the quantity of oxygen necessary to consume it.

If, then, a combustible in a fine state of division be ignited with the oxide of an easily fusible metal which yields readily its oxygen, it is evident that the weight of the button obtained will also be in proportion to the amount of oxygen abstracted from the oxide, thus affording an easy method of comparing the heating powers of different combustibles.

Experiments of this description, however, require to be conducted with extreme precaution, in order to insure success; as, in the first place, any trifling error in the observed weight of the combustible is multiplied some thirty times on the resulting button of lead; secondly, the substance requires to be in a state of extreme division; and, thirdly, every precaution should be taken to avoid the action of the reducing gases of the furnace. In order, therefore, to remove these causes of error, we proceeded as follows:—

Five grains of the substance, powdered and sifted through the finest wire gauze, were intimately mixed on a sheet of glazed paper, with about 1500 grains of litharge, which was introduced into a perfectly clean earthen crucible, and on the top of this was added about 500 grains of pure litharge. The cover was then luted on with fine fire-clay, with which the whole outside of the crucible was also coated, in order to render it impervious to the reducing gases of the furnace. The crucible was then brought near the fire to dry, and when all the water had evaporated, it was placed in a furnace in which a charcoal fire was already lighted, and allowed to remain about 15 minutes; the cone *a*, plate 2, was then placed over the furnace for the purpose of increasing the draught; at the expiration of ten minutes it was again removed, and the crucible taken out to cool. When it had sufficiently cooled, it was broken, and the button of lead extracted, cleaned, and weighed. With these precautions, the three experiments which were made on each coal were always found to agree very closely, particularly when the substance operated on was not highly bituminous, in which case it becomes more difficult to operate with certainty.

The results of these experiments have been thrown into the following table, in which, although the results obtained from the same coals will be found to agree pretty closely, yet considerable difference will be observed in the relative weights of the buttons of lead produced by the various coals, and their economic values as shown by actual experiment under the boiler. It is, however, probable that these apparent discrepancies proceeded rather from difference of mechanical structure than from any chemical difference of composition:—

Experiments with Litharge.

Name of Coal.	Quantity operated on.	Gave of Lead.			Mean.
Dalkeith Jewel Seam	5 Grs.	128·6	133·3	134·5	132·1
,, Coronation Seam	,,	122·2	123·4	122·9	122·8
Pentrefelin	,,	152·7	152·1	153·0	152·6
Powell's Duffryn	,,	150·2	149·7	150·3	150·0
Graigola	,,	160·7	160·4	160·2	160·4
Llangenneck	,,	163·4	163·2	163·0	163·3
Ward's Fiery Vein	,,	157·7	157·5	156·8	157·3
Binea	,,	158·2	159·2	157·4	158·2
Oldcastle Fiery Vein	,,	156·7	157·2	157·4	157·1
Anthracite, Jones and Aubrey's	,,	167·0	167·6	167·6	167·4
Mynydd Newydd	,,	151·2	151·9	152·2	151·7
Grangemouth	,,	142·6	142·3	142·3	142·4
Resolven	,,	160·8	160·9	160·9	160·8
Cwm Nanty-Gros	,,	149·3	147·2	148·9	148·4
Pentrepoth	,,	158·1	153·5	155·9	155·8
Lydney	,,	129·4	130·2	129·5	129·7
Wylam's Patent Fuel	,,	145·0	143·9	143·5	144·1
Cwm Frood Rock Vein	,,	142·2	141·4	141·1	141·5
Broomhill	,,	127·0	126·1	126·9	126·6
Three-quarter Rock Vein	,,	133·0	133·2	133·2	133·1
Warlich's Patent Fuel	,,	158·9	156·0	157·6	157·5
Pontypool	,,	137·3	138·0	136·7	137·3
Porthmawr Rock Vein	,,	123·4	123·6	124·7	123·9
Bedwas	,,	141·3	140·7	..	141·0
Ebbw Vale	,,	159·4	160·0	160·5	159·9
Coleshill	,,	131·0	130·5	130·7	130·7
Wallsend Elgin	,,	146·0	145·8	144·1	145·3
Fordel Splint	,,	145·2	142·3	147·5	145·0
Slieveardagh	,,	151·7	150·0	149·8	150·5
Bell's Patent Fuel	,,	141·4	143·4	145·6	142·6

Another subject of importance in a practical investigation into the properties of coals is, the composition of the incombustible matters which they contain, as materially affecting their action on the metals. This subject, although unquestionably of more importance to the metallurgist than to the engineer, is far from being uninteresting to the latter; as, from the composition of the ash contained in a coal, he may safely infer the effects which will be produced on the grate and boiler by its employment. The time necessary to execute these analyses precluded the possibility of their being made in every case; but it is to be hoped that the results of the analysis of the ashes of eight different coals, as embodied in the following table, may serve to illustrate the subject, in case it should be thought proper to extend the inquiry in this direction.

In these experiments, the ashes were obtained for analysis by burning off the combustible matters in a muffle, and then igniting the residue with carbonate of potassa as an ordinary silicate: the analyses were afterwards proceeded with, according to the usual routine employed in such cases.

Analysis of Incombustible Matters in the Ashes of various Coals.

Name of Coal.	Silica.	Alumina and Oxide of Iron.	Lime.	Magnesia.	Sulphuric Acid.	Phosphoric Acid.	Per Centage Total.	Per Centage Amount of Coke.
Pontypool . . .	40·00	44·78	12·00	trace.	02·22	00·75	99·75	64·8
Bedwas	26·87	56·95	5·10	1·19	7·23	00·74	98·08	71·7
Warlich's Patent Fuel	25·20	57·30	6·90	trace.	7·85	..	99·41	85·1
Porthmawr . . .	34·21	52·00	6·199	0·659	4·12	0·633	97·821	63·1
Ebbw Vale . . .	53·00	35·01	3·94	2·20	4·89	0·88	99·92	77·5
Fordel Splint . .	37·60	52·00	3·73	1·10	4·14	0·88	99·45	52·03
Wallsend Elgin . .	61·66	24·42	2·62	1·73	8·38	1·18	99·99	58·45
Coleshill	59·27	29·09	6·02	1·35	3·84	0·40	99·97	..

Reference to Plates.

Plate 4.—Plan of boiler-house and apparatus.

,, 5.—Longitudinal elevation of ditto, showing the boiler and tanks in section.

,, 6.—End elevation, showing fire-doors, &c.

,, 7.—Details of the safety-valves and apparatus for insuring uniformity in the temperature of the water contained in the boiler.

,, 8.—Plan and section of the boiler experimented on at Par Consols Mine.

The letters of reference apply equally to each of the plates, with the exception of No. 8.

A.—Boiler-house.

B. Laboratory of the College for Civil Engineers.

C.—Barometer-room.

D.—Chimney of the experimental boiler.

E.—Furnace used for the calorific experiments.

E, F.—Water-tanks.

e, *f*.—Glass tubes of the water-gauges.

E′.—Feed-pipe.

G.—Main for supplying the tank E, F, with water.

H, I.—Iron tubes containing fusible metal, for the purpose of testing the heat of the flues by means of thermometers.

J.—Gauge for ascertaining height of water in boiler.

j j.—Water gauges of the tanks.

j′ j′.—Stop-cocks for establishing the connexion between the tanks and water-gauges.

K.—Damper.

K′, K′.—Cord for regulating damper.

L.—Iron tube for the reception of a thermometer indicating the temperature of the water in the boiler.

M.—Steam-gauge.

N.—Safety-valves.

O.—Man-hole.

O′.—Weights on safety-valves.

P.—Force-pump for effecting uniformity of temperature at the beginning and close of an operation.

P′.—Counterpoise to pump-handle.

Q, Q, Q, T, T, T.—Apparatus for obtaining uniformity of temperature.

R.—Four-way cock, used for the purpose of directing the feed-water either through the pipe Q, Q, Q, through the tube E′, or of establishing connexion with the pump P, as the case may require.

R′.—Blow-off pipe through which the steam escapes into the open air.

S.—Three-way cock used for closing the pipe E′, and at the same time establishing a connexion between the boiler and the pump P.

T, T, T.—Perforated copper bulbs for the purpose of disseminating cold water on the top of that contained in the boiler.

T′, T′, T′.—Stop-cocks for cutting off the connexion between the equalizing apparatus.

U.—Sand-bath.

U′.—Flue of ditto.

V, V.—Apparatus for the proximate analysis of coals.

X.—Tap for cleansing the boiler.

Y, Y, Y.—Sliding doors for regulating the quantities of air entering the fire-places, S, S, S.

Z. Z.—Drawers to contain charcoal running on friction rollers.

a, a.—Moveable iron chimneys for increasing draughts of furnaces.

b.—Two-way cock for the purpose of connecting the pipe E′ with the cisterns E or F at pleasure.

b′.—Cock for regulating the supply of feed-water.

c, d, e, f, g, h′.—Sylvester's patent fire-doors

A tubular boiler, D^2, has also been erected, for the purpose of making comparative statements, but has not been much used up to the present time.

Reference to Plate 8.

A, A.—Boilers.

B, B.—Internal flues of ditto.

C, C.—Flues.

D, D.—Apparatus for heating the feed-water previous to its entering the boilers.

E, E.—Feed-pipe.

F.—Fire-bars.

In the preceding memoir, reference to the plates has been made as they were noticed in it, so that plates 4, 5, 6, 7, and 8, of this volume, are mentioned as plates 1, 2, 3, 4, and 5, respectively.

Experiment on the Influence of a weak Voltaic Current upon Matter slowly deposited. By Robert Hunt, Keeper of Mining Records, &c.

In the previous volume of these Memoirs (page 451), a description was given of a very striking example of the lamination of clay under the influence of the long-continued action of voltaic electricity. Similar experiments have been since made, and all the results have tended to confirm the correctness of those previously obtained. With a desire to imitate as nearly as possible all the conditions which prevail in nature, a different system of arrangement was adopted, and the resulting disposition of the clay mass is thought to be sufficiently interesting to be described in the present volume, although it stands as an isolated experiment.

Upon the supposition that the disposition of deposited matter, as exhibited in many instances of rock formation, might be explained by the influence of electrical currents in determining the action of the molecular forces, and thus directing the order of arrangement, the following plan was adopted in an experiment designed to test this hypothesis.

A square vessel was fitted up with a zinc and copper plate placed against two of its sides, and connected with each other by a band of copper. When this vessel was filled with water, the voltaic circuit was, of course, completed, and from the chemical action induced by the water, or the salts it contained, upon the zinc plate, a weak electrical excitement ensued. With the water supplied from the Artesian well in Trafalgar Square, a tolerably sensitive galvanometer indicated a current capable of permanently deflecting the needles 57°. It should be stated that the plates were respectively 14 inches long and 8 inches wide.

This may be imagined to represent a natural basin, in which certain electrical conditions prevail, into which solid matter is slowly carried in a state of fine division, and which is gradually deposited according to the laws of gravitation, and such other forces in addition as may be called into action during the period of subsidence, it being in this experiment the force of voltaic electricity.

The mode of arrangement adopted was the following:—The vessel, which may, for distinction, be called the voltaic trough, was kept constantly full of the water supplied from the Artesian well in Trafalgar

Square, which, according to the analysis of Dr. Lyon Playfair, contains the following salts in the imperial gallon :—

	Grains.
Chloride of sodium	25·724
Sub-carbonate of soda	0·709
Bi-carbonate of soda	14·564
Sulphate of soda and potash	18·432
Sulphate of magnesia	1·157
Silicate of alumina, with trace of oxide of iron .	0·835
Carbonate of lime	3·085
Carbonate of magnesia	2·363
Phosphate of magnesia	0·043
Loss	0·276
	67·188

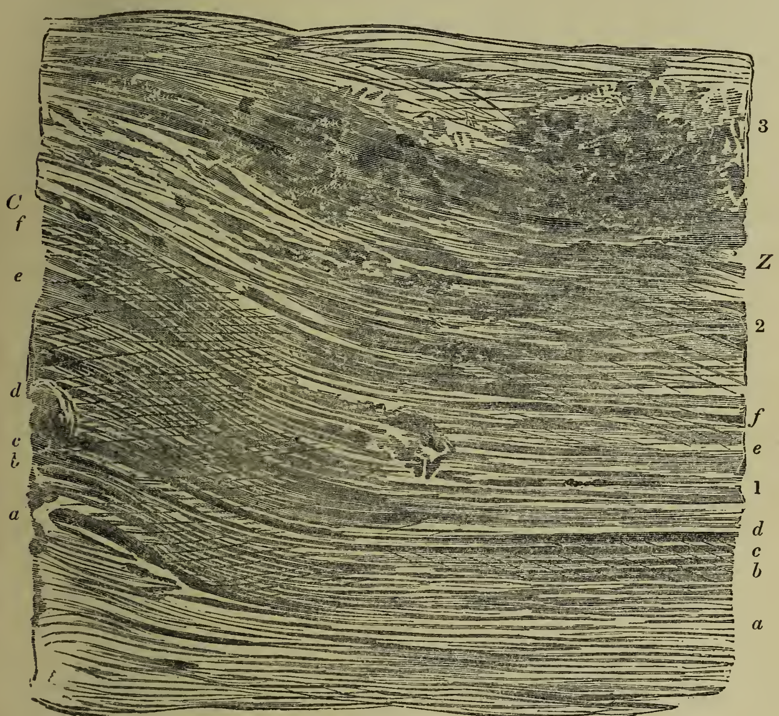
Upon an inclined shelf, which was fixed just above this voltaic trough, was placed a mass weighing about twelve pounds, consisting of about two pounds of proto-sulphate of iron mixed with ten pounds of Stourbridge clay and a considerable quantity of leaves, which had fallen during the autumn, and which were, consequently, in a state of decay. The object in mixing vegetable matter with the iron and clay was to prevent, as much as possible, the per-oxidization of the iron, as it was slowly carried down into the voltaic trough. On this mass of matter a very small stream of water from a hole perforated in a pipe connected with a cistern holding the supply for the establishment, constantly played. This, of course, carried off into the trough sulphate of iron in solution, the soluble organic matter of the leaves, and the finely divided particles of the clay. These, and also the disintegrated fragments of the leaves, the voltaic trough being securely fixed, were allowed very slowly to deposit through the water between the zinc and copper plates, the excess of water flowing over the edges of the trough.

It required a period of 10 months to wash down, in this way, the mass of matter and deposit it between the plates, and the deposition being complete, four months were necessary to evaporate, at the atmospheric temperature, the supernatant water from the trough. This being effected, another period of three months was spent in drying the clay so as to admit of examination. Thus the experiment was, altogether, continued over a period of 17 months. When perfectly dry the mass presented the following peculiarities.

The capital letters *Z* and *C* show which side was occupied by the zinc, and which by the copperplate in the experiment.

The order of deposit was very beautifully marked by the regular sequence of small bands of oxide of iron. This, it will be readily perceived, arose from the circumstance that some time was required before

the soluble sulphate of iron became oxidized on the surface of the water, and hence deposited, whilst the clay was constantly subsiding as it was regularly carried into the trough. In this way a very uniform system of beddings was produced, the lines *a*, *b*, *c*, *d*, *e*, *f*, representing most decidedly bands of oxide of iron. The irregular portions of the mass, as shown in the wood-cut at 1, 2, 3, represent irregular patches of the fragments of the leaves accumulated together.



The first remarkable feature to be noticed in this result is one which has been, to a less extent, observed in every experiment of an analogous character. All the beds, it will be seen, after observing the horizontal position for some distance from the zinc plate, suddenly show a tendency to form curved lines, opposed to the force of gravity, as they approach the copper plate. It should be noticed that the water carrying the clay, &c., flowed in on the side of the zinc plate, and that, consequently, there was a greater disposition to heap up on that side than upon the other, where the elevation was so strikingly manifested. Had this fact been observed in this instance only, where, from the flowing in and out of the water, currents must have existed, it would not have deserved attention; but when we find the same thing occurring

in perfectly still water, and always on the side next the copper pole of a voltaic arrangement, it becomes important.

On either side of the wood-cut will be seen numerous fine lines which run across the beddings, where these are curved in a very striking manner. The tendency of the two sets of lines is evidently towards the formation of a set of curves from the side Z to C. These lines, which were most distinctly marked upon the original mass, appear to form cleavage planes cutting through the stratified beds in some places, and running nearly in the same direction with them in others; thus imitating on a small scale many of the phenomena of lamination and cleavage exhibited by rocks in nature.

This result has been noticed, not as affording any strictly conclusive evidence, but under the impression that it may serve to show the importance of this class of investigation, and stimulate other inquirers to institute similar experimental examinations. Other experiments, all tending, it is hoped, to elucidate those phenomena which appear to connect electrical action with corpuscular arrangement, are in progress.

Notices of the History of the Lead Mines of Cardiganshire. By Robert Hunt, Keeper of Mining Records, &c.

The period at which the metalliferous veins of Cardiganshire were first worked is now entirely a matter of conjecture. We have no certain evidence in support of the idea that the British Princes, previously to the invasion of the Romans, derived great wealth from the mineral treasures of Wales.* Sir John Pettus, writing in 1670, says, "these works in Wales, with some others in Devonshire, Somersetshire, and Cornwall, as far as tradition can assure us, were anciently wrought by the Romans. By the Danmonii in Devonshire and Cornwall, by the Belgæ in Somersetshire, and by the Dimetæ in Cardiganshire."†

We have, in fact, no authentic account of any mining operations in Cardiganshire previously to the reign of Henry VII. (1485). That King, in the first year of his reign, created, by letters patent, Jasper Duke of Bedford, and others "Earls, Lords, and Knights" commissioners and governors of all his mines of gold, silver, tin, lead, and copper in England and Wales. Sir William Taylor was made comptroller of this commission, which was bound to pay to the King "the fifteenth part of pure gold and silver, and to the lord of the soil the eleventh part, as it grows." This commission had the especial privilege of "liberty to dig and search for any of these metals, except under the houses and castles of the king and his subjects." There is not any account preserved of the quantity of lead ore raised in this part of the Principality by the commission; but Sir John Pettus, speaking of the

* In the History and Antiquities of the County of Cardiganshire, published by Samuel Rush Meyrick, in 1810, the author speculates on the probability that the Britons wrought the mines in Cardiganshire for silver and gold. He infers this chiefly from the Triad, which celebrates Caswallan, Manawydan, and Llew Llawgyfes, as three chiefs distinguished by the possession of golden cars. In addition, this author states that no Roman coins or any vestiges of Roman workings have been found in Cardiganshire. Since the date of this publication, Roman coins, &c., have been found at Aberystwyth.

† Fodinæ Regales. In connection with the passage quoted in the text, the following also occurs:—"And Ceasar, in his Commentaries, saith, That one reason of his invading the Britons was, because they assisted the Gauls with their treasures, with which their countrie did abound. And Cimboline, Prince of the Trinobantes (wherein Essex is included), who had lived much at Rome in Augustus his time, was seated at Walden in that countie, and did (according to the Roman way) coin monie instead of rings, which might be from that mine which was afterwards discovered in Henry IV. his time in that countie." This is not strictly true, the mine in Essex never having been discovered. We find that Henry IV., by his letter of mandamus dated "11 Mai, Anno 2, Rot. 34," commands Walter Fitz Walter (upon information of a concealed mine of gold in Essex), to apprehend all such persons as he in his judgment thinks fit, that do conceal the said mine, and to bring them before the King and his Council, there to receive what shall be thought fit to be ordered.

mines of the kingdom generally, says, "Henry VII. (a wise prince) taking notice of his interest and prerogative, did in the very first year of his reign, grant this commission, and by this and other ways, raised a vast sum of money, and left his rich coffers to Henry VIII., who added to the bulk by the sale of abbies, &c. But before Henry VIII. his death, almost all the treasures of his father and his own were consumed, and what remained was left to Edward VI., an infant, whose experience could not guide him to the care of such affairs: then followed Queen Mary, who, matching with Spain, was thereby interested in the wealth of Europe, and needed no other support or inspection; so this concern (the mining commission) stood neglected for above seventy years."*

Previously to the time of the seventh Henry, although we have no accurate account of the Welsh mines, we learn from several grants and charters, that mines of lead were worked in Devonshire, Cornwall, and the northern parts of the kingdom,† particularly in the reigns of Henry the Fourth and Sixth, and of Edward the Fourth.‡ Indeed, Hollingshed,§ informs us that in the reign of Edward the First, near 1600 lbs. weight of silver was obtained in the course of three years from a mine in Devonshire, and also that silver was extracted in some quantity from

* Fodinæ Regales.

† Hen. IV. granted to Henry and John Darby the lead mines holding silver in Com-Devon.

Hen. VI. granted to John Sollers, for 12 years, the lead mines of Devonshire and Cornwall, and makes John Bottwright comptroller. This John Bottwright, governor of the mines of Berryferres (Beerferrers), complained that Roger Champernown took away 145 bowls of glance ore, valued at 15*l.* 6*s.* 8*d.*, and made profit of the same without any-thing being allowed to the King; and he gained damages for 100*l.* against Champernown.

Edward IV. granted to Gallias Lynne, William Marriner, and Simon Pert, power to search for mines within the counties of Somerset and Gloucester, paying to the King every eighth bowl of rich ore, with a clause to make mills to "*fine* and *smelt*." Richard Earl of Warwick, John Earl of Northumberland, and some others, also obtained a grant to work all mines of gold and silver on the north side of Trent within England. Richard Duke of Gloucester, Henry Earl of Northumberland, and others, obtained from the King, in the 15th year of his reign, on the 23rd March, a charter for working "mines of Blanch-lands, called Skildaw, in Com-Northumberland, and the mine of Alston Moor, called Fetchers, the mine of Keswick, in Cumberland, and the copper mine near Richmond, in Yorkshire, from Lady-day next, for fifteen years, paying the King the eighth part neat, to the lord of the soil the ninth, and to the curate a tenth." We learn, however, that in the 18th year of his reign, Edward IV. grants "upon surrender of the former grants, to William Goderswick and Doderick Vaverswick, all mines of gold, silver, copper, and lead, in Northumberland and Westmoreland, for ten years, paying to the King a fifteenth part, and to the lord of the soil and the curate as they can agree." This is the first intimation we have of the employment of German miners in England.

‡ For a detailed account of these grants and charters which relate to Devonshire and Cornwall, see Geological Report of Cornwall, Devon, and West Somerset, by Sir Henry T. De la Beche.

§ Hollingshed's Chronicle, vol. ii., p. 316.

lead in Devonshire and Cornwall in the reign of Edward the Third. It is, however, curious to observe, that in nearly all the grants, the precious metals were made the subject of particular attention, and mines of silver or gold, or of copper and lead containing gold and silver, became the objects of especial search. So anxiously, indeed, was the discovery of mines producing gold and silver regarded, that under the designation of "Mines Royal," they were made especially the property of the Crown. A "Mine Royal" was defined as follows:—"When the ore does not yield so much gold and silver as will exceed the cost of refining and the loss of the baser metal, it is called a *poor mine*. But when the ore yields gold or silver to an amount which will exceed the charge of refining and the loss of the baser ore, it is called a *rich ore*, or a Mine Royal, and is appertaining to the king by his prerogative." Upon this Sir John Pettus remarks, "And herein consists the skill and honestie of the refiner, for some have made very great products from that very ore from which less skilful essayers could extract nothing."* The uncertainty of this law was shown in the case of "Est-kyr-kyr," which mine was rich in silver, and was claimed as a "Mine Royal" by the patentees, who were supposed to produce proof in Westminster Hall, that the lead of that mine contained to the value of 60 lbs. of silver in every ton, whilst the proprietor stated that it only contained to the value of 4 lbs. of silver in a ton.†

Until the third year of the reign of Elizabeth, little attention appears to have been given to the mines of Cardiganshire.‡ That Queen, acting on the advice of her council, sent to Germany for some experienced miners, to explore the mineral districts of England and Wales. Thomas Thurland and Daniell Houghsetter came to England, and Elizabeth, in the sixth year of her reign, granted to them the mines of eight counties in England, besides those in Wales. Houghsetter and his family appear to have settled in Cardiganshire, and for four years actively prosecuted the search for mineral substances over this district. The patent under which Houghsetter and Thurland worked gave them very extensive privileges. No persons were to dig or search for Mines Royal without their license. They had power to buy any lands, and to engage workmen and purchase timber, wood, coals, &c., at "reasonable rates and prizes." In addition to this, none were to attempt to use within 20 years any instrument or tool used by the patentees, and "hath not been used within 20 years last past," or adopt their method of roasting their ores. Houghsetter and Thurland were to use their pri-

* Plowden's Reports, p. 314; and Fodinæ Regales, fol. 11.

† See Watson's Chemical Essays, vol. iii., p. 307. Ed. 1782.

‡ Camden, in his Britannia (1551), simply states, speaking of the Y-stwith, "It has at its source lead mines, and at its mouth Aberystwith."

vileges "*jointly and not severally*," and they were to be assisted and protected by all mayors, sheriffs, and justices.*

At the same time as Houghsetter and Thurland were prosecuting their mining operations in Wales, they commenced working a copper mine at Keswick, in Cumberland. This district having been previously granted to the Earl of Northumberland, that nobleman opposed their operations. The question of right was brought to trial, and the judges decided that the Queen had power to grant the right of search for metals in the lands of any of her subjects. It appears, however, that the Earl of Northumberland, not having worked, or claimed any right to work the mines in Cumberland for 70 years, "*made that questionable, which for many ages before was out of question.*"†

* The following "Abstract of the Indenture of Covenants, of the 10th October, 6th Elizabeth, between the Queen and the Patentees," may not prove uninteresting:—

"1. The Queen, reciting her former *Grant*, did covenant not to give licence to any others to *search or dig*, &c., in those eight counties, or in Wales, and that none shall search, &c., without consent of the Patentees, and that she will deface and destroy all *Tools*, Instruments, &c., save only the Patentees'.

"2. Thurland and Houghsetter covenant that the *Queen* shall have the tenth part of all *Gold, Silver*, and *Quicksilver*, found neat without melting; the tenth part of all *Gold and Silver* Eure holding 8 pounds weight or upwards in every 100 weight; and the pre-emption of all *Gold* or *Silver* found neat or tried, paying 8*d.* per ounce for Gold, and 1*d.* for *Silver*, less than the common race; and for the first five years, 2*s.* for every 100 weight of *Copper*, or the twentieth part, at *Her Majesty's* Election; and after the first five years, 2*s.* 6*d.*, or the fifteenth part, at the *Queen's Election;* and to be supplied with *Copper* upon a year's notice, paying as others; but in case the Queen do not require it, they may transport it, paying *customs* and *subsidies.*

"3. If the *Patentees* shall find a *Mine* where they cannot conveniently have *Wood* at reasonable prises, they may *transport* the *Oar*, paying half duties for every 100 weight of *Copper*, after the rate of 40*s.*, and so much ready monie as the Queen's part shall amount unto.

"4. A Covenant from the Queen, that no former Licence shall be prejudicial to the Patentees, but they shall be preferred before others.

"5. A Covenant from the Patentees, that if they find any rough Pearls, &c., the Queen to have the tenth part, and *pre-emption* of the rest, paying ready monie; and such portion of Tin as the Queen had in Cornwale, and of Lead as was accustomed in other places.

"6. A covenant from the *Patentees*, that they will bring the *Queen's* part of *Copper* and *Tin* to the place of coinage in everie shire, not above *one mile* distant by land from the Melting-place, or *twelve miles* by water; to be weighed and marked, &c.

"7. A Covenant from the *Queen*, that they and their Partners, not exceeding 24, whereof 16 be English, shall be discharged of all *Fifteenths*, &c., and other *Taxes*, so their names be certified into the Chancery within *six months*, where they may have their Warrant of Allowance, &c.

"8. A Covenant from the *Queen*, that they may bring in such *Strangers* as they need to work, being no *Enemies*, and to be *Indenizon'd* if they will.

"9. A Covenant from the Queen, that they may bring in *Victuals*, and *Tools*, and *Instruments*, for the workmen and the works, as they shall need, without *Customs, &c.*, so as entrie be made thereof in the Custom-house."

See Fodinæ Regales, fol. 50; and Plowden's Reports concerning Mines.

† "A Report of a Judgment given by the Court of Exchequer, in Hilary Term, in the 10th year of the reign of Queen Elizabeth, by the assent of all the Justices of England, in

After the settlement of this dispute, for the purpose of preventing any renewal of litigation, the Queen established a corporation of 96 persons, under the title of the *Society of the* Mines Royal, the patent of which is dated the 28th of May, the 10th year of the reign of Elizabeth (1568).*

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a case depending in the said Court between the Queen and the Earl of Northumberland, upon an information exhibited by the Queen's Attorney against the said Earl, touching a mine of copper containing gold or silver claimed by the Queen, in the lands of the said Earl; which case was argued in the Exchequer Chambers, before all the Justices of England and the Barons of the Exchequer, in Michaelmas term next before the Judgment given; and the Record thereof appears among the Records of the Exchequer, in the Remembrancer's Office, in Michaelmas Term, in which the 8th year of the reign of the said Queen ended. Rot. 239."—The Commentaries or Reports of Edmund Plowden, of the Middle Temple, Esq., an Apprentice of the Common Law, p. 310.

* An Abstract of the Letters Patent, dated the 28th of May, in the 10th year of Queen Elizabeth, incorporating for ever the Society of Mines Royal:—

1. Reciting the Letters Patent granted to *Thomas Thurland* and *Daniel Houghsetter*, dated 10th October, in the 6th year of her reign, &c.

2. Grants powers to *assign* to any Person or Persons, Parts and Portions of their said Privileges, Immunities, &c., and ratifies and confirms all Immunities, Licences, Privileges formerly to them granted.

3. Grants the said License, Immunities, Privileges, &c., unto *William* Earl of *Pembroke*, *Robert* Earl of *Leicester*, *James* Lord *Mountjoy*, Sir *William Cecile*, Knight, *Tho. Thurland*, *Daniel Houghsetter*, *John Tamworth*, and *Jo. Dudley*, Esquires; Lionel Ducket, Citizen and Alderman of London; *Benedict Spinola*, of *London*, Merchant; *Jo. Loner*, *Will. Winter*, *Anthony Ducket*, *Roger Wetherale*, *Rich. Springham*, *Jeffry Ducket*, *Rich. Barnes*, *Will. Plater*, *Tho. Smith*; Will. Bride, gent.; *Daniel Ulstet*, a German; *Matthew Field*, George Needham, and *Edmund Thurland*, all the said Privileges, &c., and incorporates them for ever, and their Successors, by the name of *The Governors, Assistants, and Commonalty* for the Mines Royal, and so to continue for ever.

4. Enables them by that name to *purchase* Lands, Tenements, &c., and to *alien*, *set*, or *let* the same, and to *sue*, *implead*, &c., and to be *sued*, &c., in any *Court*, before any *Judge*, spiritual or temporal, concerning any the affairs belonging to the said *Governors*, *Assistants*, and Commonalty, &c.

5. Power to chuse one or two *Governours*, one or two *Deputy-Governours*, and six or more Assistants.

6. Ordains *Lionel Ducket* and *Daniel Houghsetter*, *Anthony Ducket* and *Daniel Ulstet*, the first four Deputy-Governours; *Jo. Tamworth*, *Thomas Thurland*, *Benedict Spinola*, *John Loner*, *Will. Winter*, *Roger Wetherale*, the first Assistants, until the first Monday in May, 1569, and thence, if need be, till others are chosen.

7. Power to keep *Courts*, to elect *Officers*, to make By-laws, Acts, and Ordinances, when and where they please, &c., and to admit more *members*, English or strangers, &c., and to revoke Rules, Ordinances, &c. Every member to have half a quarter of a 24th part, or a Gentleman of 40 Marks per annum, in certain counties, a quarter part at least.

8. To rule and govern *Officers*, *Ministers*, *Workmen*, and *Labourers*, according to the Ordinances, &c, and to remove members and impose fines; to purchase Lands; to elect one or two officers who are called Serjeants, to collect the Fines, and to arrest Body and Goods.

9. Their Precepts to be obeyed in cities, &c., and all officers indemnified for their obedience thereto.

10. A member having a quarter part, his voice is as good as two members of half-quarter parts, and so of the next greater parts proportionably.

11. All Mayors, Sheriffs, &c., to be assisting.

Of the Society of the Mines Royal, William Earl of Pembroke was appointed governor, Robert Earl of Leicester, James Lord Montjoy, Sir Wm. Cecil, Knight, Thomas Thurland, Daniel Houghsetter and others, in all 24 persons, as assistants. The company consisted of 24 shares, and those shares were sub-dividable into half and quarter parts, so that they might consist of 96 persons, their votes being according to the proportion they had of shares.

Under this corporation the mines at Cwm-symlog and the Darren Hills, including Cwm-erfin, Goginan, Talybont, Cwm-ystwyth, Thruscott, Rhosfawr, and Tre'rddol, were worked for some years.*

We cannot now ascertain what quantity of ore was raised by this company. It is, indeed, stated by Sir John Pettus, that "they wrought several mines with good success;" but as they were eventually let for the annual rental of 400*l*., their mines could not have been very profitable to them.

Elizabeth also granted, in 1565, to William Humphreys, her assay master, and Christopher Shutz, a German,† "all mines, minerals, and subterranean treasures (except copporice and allom), which should be found in all other parts of England (not mentioned in the former patent) or within the English pale in Ireland, by the name of gold, silver, copper, tin, lead, quicksilver, cadmain or Lapis calaminaris, and all manner of ewres or ores simple, mixt or compounded, latten wire or steel, &c." It thus appears that at this time all the mining operations of the kingdom, with the exception of the tin and copper mines of Cornwall, and perhaps the lead mines of Derbyshire, were under the direction of, if not actually worked by, German miners. With a view, however, to the security of these, now rapidly extending mining and smelting operations, and also for the purpose of realising for the Crown as large a profit as possible from them, the Queen, in the tenth year of her reign, established a second corporation, under the title of "The Society for the Mineral and Battery Works." Although this society had rather the charge of the brass manufacture of the kingdom, which may, indeed, be dated from this period, than of any other particular mineral operations, yet as being established at the same time with the society of Mines Royal, and being afterwards, to a certain extent, united with it, under one President, William Earl of Pembroke, it is important to notice it, in

* These mines are designated by Sir John Pettus "Mines Royal at Coomsumblock, and the Darren Hills, Coomervin, Cogincan, Talabont, Coomustwith, Tredole, Thrustcott, and Rossvawre, which were the old Roman works."

† The patent states this Christopher Shutz to have been a workman of "great cunning, knowledge, and experience, as well in the finding of calamine, as in the proper use of it for the composition of the mixt metal called *latten* or *brass*."—Watson's Chemical Essays, vol. iv., p. 70. He is also particularly mentioned in "Opera Mineralia Explicata," by Moses Stringer, published in 1713.

any history of the mining operations of this period, from which the enlarged scale of our present mining certainly takes its rise. This company was looked upon as so important to the Crown, that the Lord Keeper, Sir Nicholas Bacon, the Duke of Norfolk, William Earl of Pembroke, Robert Earl of Leicester, William Lord Cobham, and other noblemen and gentlemen to the number of 36 were made governors.*

The mines of Cardiganshire became, during the latter half of the 16th century and the beginning of the 17th, the property of Sir Hugh Middleton. He was the sixth son of Richard Middleton, governor of Denbigh Castle, in the reigns of Edward the Sixth, and Mary and Elizabeth. He is said, in the first place, to have sought for coal, but of course, did not succeed in finding any in Cardiganshire. He appears to have left Wales and settled in London, as a goldsmith, after which he farmed the principal lead and silver mines in Cardiganshire from the Governor and Company of Mines Royal, for 400*l.* per annum.

Hugh Middleton drained the mines more effectively than they had hitherto been, and working them somewhat deeper than the German miners appear to have done, he was successful in finding very rich lead ore. It is said that the ore of one mine (probably Cwm-symlog), yielded 100 ounces of silver to the ton of lead; this may be an exaggerated statement, or probably refers only to selected samples. It is, however, certain that Hugh Middleton realized a large fortune from his speculation in the Cardiganshire mines. A clear profit of 2000*l.* a-month is stated to have been derived from Cwm-symlog and the neighbouring mines.† It is recorded that in 1604, three thousand ounces of Welsh bullion were minted at one time at the Tower. Hugh Middleton was a man of great energy of character and restlessness of disposition, and

* The arms of these societies are in themselves instructive, as showing some of the mining operations of the period when they were granted, viz., August 26, 1568.

The arms of the Society of Mines Royal were :—" Argent a mount vert; a man working within a mine, with two hammers and a lamp, all in their proper colours. On a chief azure, a cake of copper between a bezant (a coin of gold or silver, so called from its being coined at Byzantium), and a plate. On a wreath argent and azure, a demy man (called in Dutch the Schicht Master), with an escocheon on his breast, or and azure per bend inverted; in one of his hands an instrument called a wedge, and in the other hand a compass gold, mantled silver, doubled azure; supported by two men, the one called the hammerman, with a hammer on his shoulder, and the other the smelter, with a fork in his hand, all in proper colours."

The arms of the Society for Mineral and Battery Works were :—" Azure, upon the base point vert, a Doric pillar argent, supported by a lion and a gryffon armed, and langued gules. On the top of a pillar a ducal crown or. On the chief an amulet argent, between two bezants of the same. The crest on an helmet, and wreath argent and vert, two naked arms and hands supporting a cake of copper proper; the supporters an ancient man in a gown, wearing an head-piece; on it, a crescent, and holding one hand on the escocheon, in the other a pickax: on the other side a woman, holding also the escocheon with one hand, and in the other a quadrant."—Fodinæ Regales.

† Opera Mineralia Explicata; and Watson's Chemical Essays.

being now possessed of great wealth, he proposed in 1608, to bring the New River from Ware to London, promising the Lord Mayor that the undertaking should be finished in five years. Upon this truly national work, the profits of the Cardiganshire mines were expended, and Middleton was compelled to apply to the Government for money to complete his task. King James I., with his court, the Lord Mayor and the Corporation witnessed the first issue of water from the head, at Islington, and the king conferred upon the Welsh miner the honour of knighthood, and afterwards a baronetcy.

The mines of Sir Hugh Middleton, we must infer, failed to be productive after the execution of this great work, as he became so poor as to be under the necessity of working as a surveyor. We, however, find him in 1639, disputing about the mines of Tallybont, with Sir Richard Pryse, and a trial of some importance was the result.

Of Sir Hugh Middleton, we find the following quaint notice in the Fodinæ Regales :—" Had he not diverted his great gains to the making of the New River from Ware to London, certainly he would have been master of a mass of wealth; but great wits and purses seldom know how to give bounds to their designments, and by undertaking too many things fail in all."

Up to the year 1641, the Earls of Pembroke continued Governors of the Company of Mines Royal, but from that year until 1647, no Governor was chosen, but the mines of Cardiganshire were actively worked by Mr. Thomas Bushell.

Mr. Bushell was the secretary of Sir Francis Bacon, and appears to have been a man of much knowledge, aspiring to some scientific acquirements and possessing superior literary capabilities.* In his " Case of Thomas Bushell," he says, " In the mountains of Broomflyd, Tal-y-bont, Goginan, Cwm-erven, and Darran, there were great quantities of lead and silver, and I bought those mines which had been granted to Lady Middleton by King James, for 400*l.* down and 400*l.* per annum during the continuance of her interest therein."

* Bushell published, " A just and true remonstrance of His Majesties Mines Royal, in the Principality of Wales," London, 1642.

" The Case of Thomas Bushell, of Enston, in the co. of Oxon, Esq., truly stated, with his progress in minerals, and the desire of several merchants and others, that are ready and willing to advance so good a work for the benefit of the nation, humbly tendered to the serious consideration of the Honourable House of Commons, and all other persons in authority, whether civil or martial, that are desirous to advance the trade of the nation, supply the necessities of the poor, by discovering the hidden treasures of the earth, preserve the lives of many poor creatures from untimely death (who are now destroyed in their prisons for petty felonies) which might otherwise be made serviceable to the commonwealth." London, 1649.

Several other publications issued from his pen, and he edited a new edition of " Bacon's Articles of Inquiry."

Mr. Bushell worked those mines deeper than Sir Hugh Middleton, and at Cwm-symlog "he being flushed with this (Sir H. Middleton's) success, cut a measured mile to find this vein. to three and four yards deepness, at no small charge, and seeing Sir Hugh, by an engine, had wrought it several yards under water, the patentees endeavoured to bring up an *addit* to go under this work at the expense of 10,000*l.*"*

Mr. Bushell had associated with him in this undertaking Sir Francis Godolphin (who however, soon died), and Sir Edmund Wallcopp, and the workings were commenced with much spirit. In a letter to Charles, Prince of Wales, Mr. Bushell says, "Nothing doubting but that in process of time, I shall be able, with the assistance of my co-adventurers and help of their greater purse and fortunes, to make these British hills, as in situation so in esteem too, resemble the West Indies, or at leastwise those renowned mines of Saxony."

The mines were, for the period during which they were worked by Mr. Bushell, exceedingly profitable, and availing himself of the indenture of Charles I., dated 30th July, 1637, he established a mint at Aberystwith. In this indenture this privilege is granted for the following reasons:—"That there are, and likely to be, many hopeful mines discovered in the Principality of the mountains of Wales, where it is conceived are great quantities of silver, though by reason of the unskilful way of working the said mines, the same are either drowned by water when the ore comes to a considerable quantity and rich in quality, or that through ignorance the goodness of the ore is not known to the owner, and so is transported to other nations for potter's ore, out of which strangers refine silver, to the great loss and prejudice of His Majesty's Service."

Notwithstanding the large outlay the company failed in raising much ore at Cwm-symlog, and were disappointed in finding the lode worked so profitably by Sir Hugh Middleton. Large quantities of ore, however, appear to have been raised by Mr. Bushell from the works of Goginan:—"He kept a mint at work at the silver mills in Cardiganshire from the bullion he had at this mine; and is said to have clothed King Charles the First's whole army from part of his profit in this work."† Mr. Bushell also constructed a harbour at Lundy Island. It is certain that during the civil wars he sacrificed his fortune in the king's defence, and placed himself at the head of a regiment of miners, which he had raised in support of the royal cause. Aberystwith Castle was besieged and taken by the Parliamentary forces; the mines were in consequence abandoned.

* W. Waller, Report on the Cardiganshire Mines.

† Mr. Waller's Account of the Mines of Cardiganshire.

In 1658 these mines were visited by Ray. In his Itinerary he says, "September the 6th I travelled to Mahentler, and thence to the silver mills, where I saw and learned the whole process of the work of melting and refining of silver. They have two sorts of ore, the one rich of Dorrens and Cansomloch, the other poorer of Talabont. They mix these, six parts of Dorrens ore with four of Talabont, because Dorrens being rich, will not melt off the hearth without such a quantity of the Talabont. Then they carry it in a barrow from the storehouse to each smelter's several bing, where it is melted with black and white coal (that is, sticks cut into small pieces, then slit and dried)."

In his third Itinerary, 1662, Ray states, "Tuesday, June 3rd, we travelled over the sands, and so came round about by Talabont, to the silver mills, and viewed the mint at Talabont, and took as exact a description as we could of the silver works."

After the Restoration the mines returned to the Company of Mine Adventurers, of which company, Philip Earl of Pembroke was then Governor, and in 1662, the Lord Anthony Ashley Cooper, Chancellor of the Exchequer, was joined as joint Governors of the two Companies of the Mines Royal and Mineral and Battery Works. In 1668 the Earl of Pembroke retired from the Governorship and Prince Rupert was appointed in his place. They held their meetings at "Mr. Kemp's house in Sheer Lane (who is registrar to both Societies), where all the books of the records remain, and either there, or at his chamber in the Inner Temple," says Sir John Pettus, who was himself a Deputy Governor, "all who are desirous to interest themselves in this concern, may receive directions and satisfaction."

Sir John Pettus published his Fodinæ Regales in 1670, at which period these mines were worked, but "not effectually."

The extent of the workings at this date may be judged of from the following particulars, which form part of an account taken in 1667, and given by Sir John Pettus.

"A stream of water three miles from Tallibont falls into four great wheels, whose turning guides the rising and falling of the bellows and stampers."

"At the great stamping mills there are five hearths, with backs, cheeks, work-stones, iron-plates, &c."

"Five pairs of large smelting bellows, &c.; one great pair of scales with weights."

Besides these, numerous small articles are named, and in this department 10 men are employed.

The materials in the ore-house, the old mint-house, the stamping mills, the refining mills, the red-lead mills, are then stated, and it appears that in these 11 men were employed.

At "the Mines Royal at Tallabont," four washers, a smith and a carpenter were employed. The list contains the number of tubs, sieves, and then states "that four dozen ore bags lie in the carriers' hands and custody."

In 1670 was published "Articles of Agreement and Subscription between H. R. H. Prince Rupert and divers noble and honourable persons and others, undertakers for working the Mines Royal in the counties of Cardigan and Merioneth, in the Principality of Wales."* From these we learn that "the undertaking was to consist of 40 shares and no more, of 100*l.* each." Mr. Edward Backwell was appointed treasurer; the Committee consisted of Sir Paul Neville, Kt., Sir Francis Cobb, Kt., and seven other gentlemen, and they were to meet at the Rolls Chamber in Whitehall "every Tuesday, in the afternoon, in Term time, and during the actual sitting of any Parliament, and in the forenoon out of Term and Parliament not sitting." It was agreed that the "undertakers" should lease from the Society of Mines Royal, for one-and-forty-years, the mines "of Comsymloch, Goginian, Combmarvin, and Tallibont," in Cardiganshire, and "all the mines near Bermouth," in Merionethshire. These articles also contain an agreement, "that the said undertakers shall likewise proceed to perfect one agreement for the purchasing in of a lease of certain smelting and refining mills, with appurtenances, in Skybory Coed, in the parish of Llanyhangell Generoglyn, in the said county of Cardigan."†

The directors of this company quarrelled amongst themselves, and the mines were neglected. One Mr. Sheppard undertook to manage the affairs of the company; but he appears to have been also unsuccessful.

In 1690 some mines were discovered on the Gogerthan estate, belonging to Sir Carberry Pryse, of a very valuable character. The ore is said to have been so near the surface of the earth, that the moss and grass did but barely cover it. Sir Carberry Pryse, under an Act of Parliament, passed in the 1st year of the reign of William and Mary, took in several partners, and "divided his waste into 4000 shares."

* London: Printed for William Phillips, at the Black Raven in Chancery Lane.

† The following are the salaries paid at that time by this Company to their officers:—

Henry Rumsey, Esq., Chief Steward . .	per Annum	£200
His Clerk	,,	30
Major Richard Hill, Master Worker . .	,,	100 marks.
Edward Hacklett, Steward	,,	£30
Mr. Meredith Lloyd, Clerk of the Mines .	,,	30
Mr. Henry Kemp, Register	,,	20
Thomas Greenfield, Serjeant	,,	10

He sent to the north of England and secured the assistance of Mr. Waller, as his agent, at 200*l.* per annum. The lessees, under the Society of Mines Royal, laid claim to these mines, and in 1692 the lawyers were actively employed in prosecuting an action between Sir Carberry Pryse and Mr. Sheppard, the Agent of Prince Rupert's Company.

Sir Carberry Pryse, with the Duke of Leeds, the Marquis of Caermarthen, and some others, procured an Act of Parliament (5th of William and Mary), "which empowered all the subjects of the Crown of England to enjoy and work their own mines, notwithstanding they contained gold and silver, provided the King and those who claimed under him, may have the ore, paying the proprietors for it upon the bank, within thirty days after it is raised, and before it is removed for lead; lead nine pounds a ton; copper ten pounds," &c.

It is stated that, upon the passing of this Bill, Sir Carberry Pryse, anxious to communicate the glad intelligence to his mining friends, rode from London to Esgair-hir in forty-eight hours.

Sir Carberry Pryse died without issue, and the mines passed to Sir Humphrey Mackworth, who purchased Mr. Edward Pryse's interest and share for 15,000*l.* The Gogerthan property, however, still continues in the possession of a branch of the family.

In the year 1699 Mr. Waller made a report on the condition of these mines, which was afterwards referred to Sir Humphrey Mackworth and Wm. Player, Esq., of Gray's Inn. This document shows that about 100 men were at the time employed. It does not appear that any quantity of ore was raised, but the miners were working upon several veins which were then considered of great promise. The ore was at this period sent to Neath, in Glamorganshire, to be smelted, where Sir Humphrey Mackworth was making great improvements in all the arrangements necessary for loading and unloading vessels, and for all the operations for refining silver and manufacturing litharge.*

* Every effort was now made to raise these mines in the estimation of the public, and even the efforts of the Muses were brought into play. In this year, a long poem "To Sir Humphrey Mackworth, on the mines of the late Sir C. Pryse," was published by Yaldon. The nature of this composition may be judged by the following lines :—

"Thy fam'd inventions, Mackworth, most adorn
The miser's art, and make the best return,
Thy speedy sails, and useful engines, show
A genius richer than the mines below.—
Thousands of slaves unskill'd Peru maintains,
The hands that labour still exhaust the gains;
The winds, thy slaves, their useful succour join,
Convey thy ore, and labour at thy mine;
Instructed by thy arts, a power they find,
To vanquish realms where once they lay confined."

In 1698 arose the novel scheme of the Mine Adventure, of which a prospectus, with the following title, was first put forth :—

"The Mine Adventure, or an Expedient. First—For composing all differences between the partners of the Mines late of Sir Carberry Pryse. Secondly—For establishing a new method for the management thereof, and thereby (instead of an Arbitrary Power over the Mines and Stock of all the Partners in one person) settling an equal and fair constitution for every person concerned. Thirdly—For granting several Charities out of the same to the Poor of every county in England and Wales, without Prejudice to the Partners. Fourthly—For enabling the Partners to employ a much greater stock therein, and consequently (in the same proportion) to advance the gain and profits thereof. Fifthly—For discharging all Debts, Duties, and Demands chargeable upon the said Mines, originally occasioned by several Expensive Law-suits between the said Sir Carberry Pryse and the Patentees of Royal Mines. And sixthly—For raising a large Stock of 20,000*l.* (clear of all manner of incumbrances) for the working and carrying on the said Mineral Works to the great advantage of the King and Kingdom. Proposed by Sir Humphrey Mackworth. Perused and settled by Eminent and Learned Council in the Law; and finally established in two Indentures made and executed by the present Partners, and which shall be Inrolled in the High Court of Chancery."

Such were the high pretensions of those interested in the scheme of the Mine Adventure. Mr. Waller, writing at the same period, in the form of a circular, to the people of England, gives the most exaggerated account of the Cardiganshire mines. "This Adventure," says he, "is recommended to the world as an undertaking, whereby not only His Majesty's customs, and the trade and wealth of England will be advanced by the lead and copper, being commodities and manufactures of our own country, and thereby the exportation of our coin and bullion, obtained with so great difficulties from the Spanish Indies, in great measure prevented."

After giving a section of the veins on the estate of Sir Carberry Price, he adds, "And thus you see that there are eight large veins of silver, lead and copper ore, lying near together in one mountain, where one level serves to drain the water from all or most of the said veins, and which (it is presumed) can't be parallel'd in any part of the Christian world." And, again, having set forth the advantages of the situation of these mines, it is stated, 'From all which it plainly appears (by calculation) that, with a stock of 20,000*l.*, and good management, the said mines would yield an yearly profit (over and above all charges) of one hundred seventy-one thousand nine hundred seventy pounds nineteen shillings and nine pence for lead, besides the silver, which, is believed, will yield, one tun with another, about 14*l.* in silver

per tun of metal, and may, in all probability, double this valuation of the mines. 'Tis plain that this nation can never want silver, if these veins are carried on with a large stock, and will yield such large quantities of oar, at so small an expence, as is herein mentioned. This valuation may seem incredible to many persons not skilled in the art of mining, nor acquainted with the vast advantages that may be made from mineral works, especially so large, and so well situated near the sea as these are. But if demonstration will not convince, 'tis in vain to use any other arguments." Appended to this account, is a rude map of a part of Cardigan, of which a copy is given, Plate 9. In an abstract of the accounts rendered by Mr. Waller to the Company in 1700, we have some returns relative to wages and the expenses of smelting in Wales ; a copy of one of these accounts is given in the accompanying note.*

* An account of the refining 72 tons 1 qr. 10 lbs. lead at Neath, from the 16th July, 1699, to 16th March following, viz.:—

			£. s. d.	
The lead refined 72 tons 1 qr. 10 lbs., valued at Neath, at 8*l.* per ton,			576 2 8	
The charge of refining said lead :—				
To 120 bushels of bone ashes expended, at 4*s.* per bushel		£24 0 0		
To 15 weigh of coals, at 20*s.* per weigh		15 0 0		
To wages to workmen as follows :—				
Paid John Grimshaw, for 21 weeks, at 21*s.* 6*d.*	£22 11 6			
Paid Samuel Ackroyd, for ditto, at 16*s.* .	16 16 0			
„ Thomas Humbledon, for ditto, at 10*s.*	10 10 0			
„ William Dalton, for ditto, at 9*s.* . . .	9 9 0			
„ Thomas Forrest, for ditto, at 9*s.* . . .	9 9 0			
„ Michael Parker, for ditto, at 8*s.* . . .	8 8 0			
„ John Jennings, for ditto, at 8*s.* . . .	8 8 0			
„ Robert Reynolds, for ditto, at 7*s.* . . .	7 7 0			
„ Richard Gascoigne, for ditto, at 7*s.* .	7 7 0			
		100 5 6		
To 308 casks for litharge, at 20*d.* each . .	35 13 4			
To heading ditto, and nails, 2*d.* per cask .	2 11 4			
To seven dozens of candles expended, at 5*s.* per dozen	1 15 0			
To smith's work for mending tools . . .	1 10 4			
		41 10 0		
Whole charges of refining said lead			180 15 6	
				756 18 2
The value of the lead, and the charges of refining it :—				
The said lead refined, produced,—				
660 ounces of bullion, at 5*s.* 6*d.* per ounce			181 10 0	
And 74 tons 18 cwt. 2 qrs. 20 lbs. litharge, valued at Neath at 10*l.* per ton.			749 6 9	
				930 16 9
By the above account it appears that the bullion and the litharge produced from the said lead, amounts to			930 16 9	
That the lead and charges of refining it exceeds not			756 18 2	
And consequently there is gained by refining the said lead . .			£173 18 7	

Which is 22*l.* 19*s.* 10*d.* per cent. clear profit, errors excepted.

Thomas Horne.

In the year 1700 the Company was regularly formed, under the title of the Governor and Company of Mine Adventurers of England.

They were governed by a General Meeting, a Grand Meeting, and a Select Committee.

All partners who had three shares had a vote in a General Meeting; all who had ten shares were members of the Grand Committee; and the Select Committee was chosen every year at a General Meeting, out of those partners who had twenty shares. To this Select Committee the active management was intrusted.

The General Meeting was held on every second Thursday in May and November, when the Committees were elected by ballot, vote by proxy being allowed under letter of attorney.

The workings at the mines were managed by a Grove Steward and a Pay Steward. The Grove Steward was the steward of the mines; he had to direct the miners and workmen; to set them bargains; to take care that the works were regularly proceeded with, and effectually carried on; to see the ore weighed to the carriers, and to grant warrants to the Pay Steward for the payment of the miners according to their respective bargains.

There appears to have been the same customs observed at this time as prevail at the present.

"When the Steward of the Mines has a bargain to set out he comes into the field, and there openly and publicly proclaims to the miners the taking of such bargain, and he or they that comes to the lowest rate have the bargain granted to them." Subsistence money was paid every week, and they "made a clear pay every six weeks."

It would appear from the statement of Mr. Waller, the principal Agent, that they were working upon six veins of lead and on two of copper. Other veins were discovered, but they were not at all productive.

Some samples of the Cardiganshire ore were examined at Stationer's Hall. The worst gave two-thirds lead, and the best three-fourths. The price per ton of ore is stated to have been "5*l.* and upwards over and above all manner of charges whatsoever."

A few further particulars of this mining company may not be quite without interest.

The shares were disposed of by drawing lots. Those who drew blanks were only creditors of the mines; they were to receive 6 per cent. interest, but to have no vote in elections, nor any interest in the capital. Those who drew shares became members of the company, and had voices in the management of the affairs, and a fair proportion of the dividends. It does not, however, appear that these dividends were of much importance. The following is a tabular view of the workings of these mines under this Company, as given by Mr. Waller:—

Name of Mine.	Nature of Ore.	Number of Lodes worked up to this date.	Number of Lodes known, but not yet worked.	Depth of Audit or Level.	Boundary of Set.	Size of the Lodes.	Assay of Ore Silver per Ton.
				Feet.	Miles.	Feet.	Ozs.
Bwlchyreskirhir . . .	Lead . . / Silver . .	3	3	..	37	4 to 8 / 3	
Bwlch-Laninogg . . .	Lead . . / Copper .	1	1*	270	..	2 to 5	
Cwmsumblock . . .	Lead . . / Silver . .	1	..	192	..	2	
Goginian	Lead . . / Silver . .	2	..	300	..	..	44
Brinpica	Lead . . / Silver . .	2	..	210	..	1½	44
Cwmarvin	Lead . . / Silver . .	1	..	54	..	4 in. to 3	44
Pencraiddy	Lead . . / Silver .	1	1	120	..	3 to 5	44
Ystimtean	Lead . .	1	5	..	..	1 to 2	
Cwmustwith	Lead . .	2	..	..	..	Various† / ½ to 1½	
New Mines	..	..	1	..	..	6 feet.	

* Producing 1 in 5 of fine copper.

† "Silver vein runs in bellies of ore from 4 yards broad to 7 yards, and from 10 yards long to 30 yards, and from 4 yards high to 7 yards, then connected by leaders, of an inch thick, for 5 or 16 yards."

Professedly a twelfth part of the profits of the mines was to be appropriated to charitable uses. "For the augmentation of poor vicarages in Wales; for the assistance and encouragement of such persons as shall endeavour the conversion of infidels in the Indies; for the relief of Greenwich and other Hospitals; of poor miners and labourers at the works, their wives and children, and in time, of other poor people in most of the great corporations in the kingdom." The disposal of this twelfth part of the profits was placed in the hands of Sir Hugh Mackworth, but it would appear that they were never more than sufficient to allow of his building a small school in Wales.

In 1700, Sir H. Mackworth took a lease of Margaret Lewis of Gallt-vadog, and her son R. Lewis, of the mines at Pwll-yr-Enaid, Bwlch-cwm-Ervin and Ryginan for 99 years, paying in consideration only 50*l.* in hand. The Mine Adventurers had also a lease of Cwmsymlog, which mine they worked for some years. Sir Humphrey states, that under his management they drove and carried levels to 28 mines.

In 1704, Queen Anne granted the Company of Mine Adventurers a charter of incorporation, the Duke of Leeds being Governor, and Sir Humphrey Mackworth Deputy Governor.

The quantity of lead ore raised, notwithstanding all the pretensions of those with whom this scheme originated, was never large. In an account of Mr. Waller's we have the following summary of the state of affairs :—

	£.
The original stock of this company	20,000
Lessened by building houses for the miners, carriage of ore, stones, and other incidental charges	5,000
Stock in litharge, lead, and silver, in merchant's hand . . .	4,000*

In 1709, disputes arose amongst the members of this company, and Sir Humphrey Mackworth and Mr. Waller quarrelled, and accused each other of unfair dealings. Mr. Waller was discharged, and the whole affair broken up, much to the dissatisfaction of all the shareholders, who unscrupulously charged Sir Humphrey Mackworth with fraud and deception.

Mr. Waller petitioned the House of Commons, and a Committee of Inquiry was ordered.

It is evident from their proceedings, that this Committee was not satisfied with the conduct of Sir Humphrey Mackworth, and we find they made several orders to the effect following :—" Ordered, that a Bill be brought in to prevent the said Sir Humphrey Mackworth, William Sheres, and Thomas Dykes, their leaving this kingdom, and their alienating their estates until the end of the next Sessions of Parliament, and that Mr. Benson, Mr. Aistaby, and Sir Richard How do prepare and bring in the Bill."

Sir Humphrey Mackworth published a defence of his conduct in 1710, and some of his friends published " A Vindication" as late as 1720. Numerous pamphlets and small volumes, written by the shareholders and others, were given to the public between the years 1700 and 1737, during the whole of which time, such large interests were involved in " The Mine Adventure," that the question appeared to excite great attention.†

From the published lists we find there were 650 shareholders. These

* From this account we learn incidentally, that litharge was never made a marketable commodity in England until Mr. Robert Lydall, the chief operator to this company, patented a process for its preparation. It was usually sold at 20*l.* per ton, " but from these works it is sold at the price of red lead."

† The following is a list of the various pamphlets, &c., published on "The Mine Adventure :"—

Mine Adventure—Case of the Mine Adventure, folio.

Bill for the relief of the Mine Adventurers, folio.

List of the Adventurers, folio, 1700.

Familiar Discourse, or a Dialogue, concerning the Mine Adventure, 8vo, London, 1701.

——————————————— 8vo, London, 1705.

Proceedings of the Mine Adventurers, folio, 1704.

Rules, Orders, &c., of the Company of the Mine Adventurer, 4to, London, 1706.

embrace some of every class, from peers, peeresses, bishops, and knights to farmers and humble shopkeepers. From the "list of persons making claims of sums respectively due to them for stock, bonds, &c., the names beneath are taken at random as affording an idea of this very extraordinary bubble scheme.*

Of the final settlement of this matter we have no accurate information. At the same time that the Mine Adventure was in progress, but unconnected with it, some mines were worked by Sir Thomas Bonsall.

In 1744, the following mines only were working, and few men were

---

Proceedings of the Company of the Mine Adventure, in their Transactions with Mr. D. Peck, folio, 1707.

List of the Company of Mine Adventurers, folio, 1708.

Proceedings of the General Court of the Mine Adventurers, folio, 1708.

Report of the Committee of the House of Commons relating to the Mine Adventurers, folio, London, 1710.

List of the persons who have made a claim upon the Company of Mine Adventurers, folio, 1711.

List of the Creditors of the Company of Mine Adventurers, 4to, London, 1712.

List of the Proprietors of the Company of Mine Adventurers qualified to vote, folio, 1727.

——————————————————— folio, 1730.

Abstracts of the present State of the Mines of Bwlchyr-Eskir-Hyr, 8vo, London, 1700.

Mine Adventure, Answer to several Objections against, 8vo, London, 1737.

Mine Adventure, Settlement of, folio.

Journal of the Mine Adventurers, Stockholm, folio, MS.

Account of the Proceedings of the Mine Adventurers, folio.

Advantage of the new Scheme of the Mine Adventurers, folio.

Reason for and against the Bill of the Mine Adventurers, folio.

Remarks on a Paper entitled Observations on the Bill relating to the Mine Adventurers, folio.

Answer to a Paper published by one Bateman against the Mine Adventure, folio.

List of the Governors and Court of Directors of the Company of the Mine Adventurers, 4to.

Case of the United Creditors of and Proprietors of the Mine Adventure, folio.

	£
* The Right Hon. Earl of Bollingbroke	700
Rev. Dr. Samuel Blithe	1,200
Thomas Bretton, Esq.	3,550
Mrs. Elizabeth Dillingham	1,770
The Duke of Leeds	6,440
The Hon. Colonel Nassau	1,219
Richard Sterne, Esq.	14,098

The claims of the various branches of the Mackworth family are curious:—

	£.	s.
Buckly Mackworth, Esq.	2,037	14
Sir Thomas Mackworth	4,335	0
Mrs. Ann Mackworth	6,663	0
Mrs. Mary Mackworth	6,613	0
Herbert Mackworth, Esq.	6,556	0
William Mackworth, Esq.	6,510	0
Sir Humphrey Mackworth	61,740	0
Kingsmil Mackworth, Esq.	6,530	0

employed:—"Pencraigddû, Grogwynion, Cwm Ystwyth, and Eurglawdd." Some of the managers of the "Mine Adventure" retained, but did not work "Cyginan, Brin Picca, and Bwlch cwm Ervin," whilst they gave up Esgair-hir, Talybont, Cwm-symlog, and most other leases. Shortly after this, a Flintshire company worked "Darren, belonging to Mr. Griffith of Pen-y-pont-peren, Ynishîr, Talybont, or Gallt y Crûb, Escair-hir-Caneinog, Bryn Llwyd, and Cwm Sebon, belonging to Mr. T. Price."

In 1751, Mr. Lewis Morris published "A Short History of the Crown Manor of Creuthyn in the county of Cardiganshire;" we have a long discussion on "Mr. Powell's Scheme of converting all the King's Commons in Cardiganshire into Freeholds, in order to deprive His Majesty of his Mines and other Royalties in that County." In 1757, and for many years after, Mr. Morris derived a large income from the mines he was then working.

We cannot obtain any authentic account of the progress of mining in Cardiganshire from this period until 1810, when Sir Samuel Rush Meyrick published a statement of the mines in active working, from which the following list has been taken:—

Cwmsymlog, yielding about 40 ounces of silver to every ton of lead.

Darren Vawr, giving 35 ounces of silver to the ton of lead, and twelve hundred weight and a half of lead from a ton of ore.

Goginan, producing ore of a similar character, which sold at that time for 11*l.* per ton.

Daren Vach.

Cwm Ervyn.

Llanvair. In 1806 the ore from this mine sold for 27*l.* per ton; containing from 60 to 80 ounces of silver to the ton of lead.

Mynydd Bach, discovered in 1798, but not then fairly worked.

Escair Vraith, producing principally copper ore, which, in the year 1791, sold for 25*l.* per ton.

Ynys Cynvelin. Lead and copper.

Escair Hir. In 1806 the ore sold at 18*l.* per ton.

Allt y Crûb, worked by a Shrewsbury company.

Llewernog, worked by Sir Thomas Bonsall, and by Mr. William Poole; producing lead ore and sulphuret of zinc.

Ystym Tuen.

Hên Vwlch.

Aur-glawdd.

Moel Gôch ore sold in 1806 for 16*l.* per ton.

Pen-y-banch.

Nant-y-Crier. Sulphuret of zinc and lead. Lord Powis has a grant of it from the Crown, and Mr. Sheldon holds it of Lord Powis.

Gellaw Erin ore sold in 1806 for 19*l.* per ton.

Rhûv yr Agos. Sulphuret of zinc and lead.

Bron y Goch, lead ore sold for 18*l.* per ton. Black jack for 4*l.* 10*s.* per ton.

Llwny Wnwch.

Grogwnion.

Log y Lâs. A level was begun about 1790.

Escair y Mwn. In 1751 three workmen took a year's lease of Mr. Morris, and in that time cleared 1300*l.* each. Lord Powis has a grant of it from the Crown.

Cwmystwyth.

Nant y Meirch. Sulphuret of zinc, which in 1806 was sold for 5*l.* 10*ls.* per ton.

Cwm-yr-anner-ddu; Nant y Cagl; Pen-y-fordd Goch; and Pen-y-sarn, not worked.

Rhysgog.

Escair gad-vach; Cwm-trinant; Tan-y-gaer; Vach ddû; producing but very small quantities of ore.

These brief notices will, it is hoped, afford a general view of the progress of mining industry in Cardiganshire up to 1810. By careful reference to original authorities many errors which have prevailed have been corrected, and great caution has been observed to prevent the introduction of any statements which did not appear well authenticated.

On the Mining District of Cardiganshire and Montgomeryshire. By

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I.—*General View of the Phenomena.*

THE metalliferous district of Cardiganshire and Montgomeryshire is a tract of land ranging about 40 miles in a N.N.E. and S.S.W. direction, and varying from 5 to 22 miles in breadth, a tract formed exclusively of the clay slates and gritstones correspondent with or underlying the lowest beds described by Sir R. Murchison, in his Silurian System, and exhibiting a roughly-featured, sometimes even corrugated, surface of hill and dale, which seldom rises into a bold peak, or breaks into precipitous hollows.*

Large portions of this principal district are as yet not known to contain mineral veins, and the intermediate parts, which are best characterized by their productiveness, are defined by certain limits, intimately related with the lithological character of the rocks. The prevailing strike of the beds is from N. by E. and S. by W. to N.N.E. and S.S.W., and, in the same direction, bands of various width may be traced in which a number of the most successful mines have been worked; and whilst, in many of these minor subdivisions, the approximate limit of the productive band is, in a marked manner, coincident with a change in the geological features of the country, in others it is more vague, and would appear to follow laws for whose investigation we are hitherto unprovided with sufficient data.

It would here be out of place to enter on the subject of lodes, or mineral veins, generally, or of that division of it which includes those occurring in the Protozoic rocks of Wales; for, since it is considered desirable that descriptive memoirs should be published from time to time, simultaneously, or nearly so, with the maps of the Geological Survey, it is only after the remainder of the ancient slaty rocks of Wales, including those of Merioneth, Caernarfon, and Denbigh have been surveyed, that the subject can be examined under its wider bearings; and the object of the present paper will be chiefly to point out the distribution and character of the lodes in Cardiganshire and Mont-

* It is scarcely possible to obtain a more vivid portraiture of the superficial features of this highly-contorted country than that which is presented by the beautiful and truthful shading of the Ordnance map.

gomeryshire, and to describe briefly the economical results accruing from their discovery.

To those prepared to found their opinions on the precedents of most other mining districts, that before us offers an anomalous, and perhaps somewhat unattractive, character. The presence of ore cannot here be directly ascribed to the proximity of granites, or porphyries, since this happens to be the only large portion of the slaty rocks of Wales, in which not a vestige of any rock of igneous origin is met with. Moreover, whilst their occurrence in the beds of only one epoch renders it impossible to fix their *geological date*, the various direction of the lodes gives no clue towards the determination of their *relative age ;* for however dissimilar their strike may be, there appears to be no such decided difference in their filling, nor such evidence of the passage of one through another as to allow of their division into separate groups upon this principle. Again, the appearance of the veins at their " back," or " outgoing" at the surface, is, in most cases, so slightly marked as to appear of no account to the miner accustomed to districts abounding in pyritous ores ; for, whilst in such cases a readily induced decomposition gives rise to the " gossan," or " chapeau de fer," so commonly considered a test of the riches below, the usual absence of these minerals in Cardiganshire, and the preponderance of slate in the matrix, leave the mass without any such peculiarities of colour or structure as would at once attract attention.

It is also partly owing to the above cause, and partly to the nature of the prevailing rocks, that the neighbourhood of the mines, when at a moderate elevation above the sea, is rarely marked by that character of sterility generally observed in regions which are favoured in their subterranean treasures. The wanderer who pursues his winding way along the beautiful valley of the Rheidol, or traces up some of the many other streams which flow east and west from the Plymlumon range, is often struck with surprise to find himself, after a succession of purely rustic scenes, close to the mouth of a gallery, perhaps long ago abandoned, which opens in the midst of a wood of oaks, or upon a fertile meadow, where the light tint of the conical " burrow," or pile of excavated rubbish, offers a marked contrast to the verdure of the surrounding landscape.

If we commence with a general view of the district, it will be seen that a belt of land (forming the " Aberystwyth group" of Professor Sedgwick), stretching along the sea-coast, and occupying a width of 4 miles on the N. of Aberystwyth, and 12 miles near Aberaeron is, as far as yet known, destitute of mineral veins ; and the same may be said of the high range of mountain on the E. and N. of Tregaron, of the principal group of Plymlumon fawr, of the hills east of Llanidloes, and of

the elevated plateau between that town and Llanbrynmair, whilst it is worthy of remark that in each of these cases a great preponderance of arenaceous beds obtains, and, although in other parts of the district they occasionally intervene, they always die away again, as the character of the deposit changes from ancient sand to mud, in the course of a mile or two. We are thus provided with a result of observation which, though it may be modified by future discoveries, will be useful as a rude guide to the limits of the field of our more immediate inquiry.

A portion of the two counties being thus divided off from the rest, it will be found, when the complexity of ever-varying inclination and strongly-developed cleavage have been overcome by patient labour, as appears from Prof. Ramsay's horizontal sections across South Wales, that the whole width of our district is constituted by a succession of rolls or undulations, of what may *in the main* be termed the same series of beds, varying in lithological character from a soft shale through many varieties of slate, flag, and argillaceous rock, to a coarse gritstone and conglomerate. The zones of productive mines will be parallel to the axes of these undulations, and, by imagining lines of division to run in the same direction, S. by W. to N. by E., we may obtain six groups, which, though perhaps arbitrarily chosen, exhibit, in some respects, distinctive characters, and afford a more consistent classification than can otherwise be obtained.

The first group, beginning on the west, borders on the unproductive grits of Aberystwyth, and includes the mines of Tal y Bont, Penybont-pren, Llancynfelyn, and Tre'rddol, producing lead ore containing a very trifling amount of silver, a little zinc blende, and, in two or three instances, copper pyrites. The lodes are of small width, and the strata, with a moderate westerly dip, are perpetually running into the fissile variety of slate which injures the regularity of their metallic contents.

The second is a band of greater importance, which, about two centuries ago, when known as the "Welsh Potosi," returned enormous wealth to the enterprising adventures of Sir Hugh Myddleton and Mr. Bushel, whilst at the present day it is distinguished by the mines of Goginan, Cwm Sebon, Cwm Symlog, Daren, Pen y Cefn, and Esgair Hir. The slaty rocks here assume a paler tint, inclining to a bluish and greenish gray, offer a peculiar and almost greasy lustre, and exhibit on the whole a more massive bedding, in consequence of which it would appear that the mineral veins increase in width, expanding in some cases to upwards of 20 feet; the lead ore is generally argentiferous, sometimes to the amount of 38 ozs. in the ton of lead.

The third division, ranging from Ystrad Meyric to the Devil's

Bridge, and along the course of the Rheidol, comprehends a number of mineral veins, varying in character nearly as much as the rocks which they traverse; thus, Llwyn Malys lode is remarkable for containing a per centage of silver, though at a distance from other argentiferous mines, Fron Goch for its large deposits of galena and zinc blende, the Estymteon lode for its bands of iron pyrites, and that on Pen Drosgol for its manganese ore, whilst the beds exhibit every variety between the gritstones of the Mynydd bach and of Drosgol, the dark fissile slates on which various quarries have been opened, and the indurated gray argillaceous rock in which the mines generally occur.

The fourth band, striking from Llampeter to the central range of Plymlumon, will include the highly argentiferous lead lode of Llanfair Clydogau, and then, after an interval of some miles on the north, several of the localities most productive of common lead ore, accompanied by zinc blende and calc spar, the principal mines being known as Esgair y Mwyn, Logaulas, and Nant y Creiau. To the north of Plymlumon Fawr, where the beds for the most part consist of fissile shales and gritstones, not a trace of ore has yet been discovered.

The fifth zone, ranging along the east of the Plymlumon ridge, comprises the remarkable and extensive mines of Cwm Ystwyth, some slightly worked veins in the upper valleys of the Wye and Severn, the important works of Delife and Esgair Galed, and the group of parallel lodes near Llanbrynmair. Beginning with the elevated mass on which the Teifi pools are situated, the southern part of this division is marked by a frequent intercalation of arenaceous matter, which, to the north of the Delife mines, is succeeded by argillaceous shale; whilst it is remarkable that, throughout the former area, copper pyrites is so common a constituent of the lodes as to have been separately returned from several of the mines, as Copper Hill (Cwm Ystwyth), Siglen Las, Hafod Feddgur, Cwm Rhicet, and the Delife.

The sixth division, circumscribed as it is on the east and north by the gritty beds which crop out from beneath the Wenlock Shales, comprehends a few mines around Llanidloes, as Bryn Dail, Pen y Clyn, and the Gorn; but these are characterized by the remarkable fact, that the ore of lead is accompanied by witherite and baryte, neither of which minerals have yet been met with in any other part of the district we have considered.

In the same zone might be included another group of plumbiferous veins occurring in a remote part of the county, around Llangynnog, at a distance of nearly 30 miles from those above mentioned; they traverse the slaty rocks where they emerge, in their regular line of strike, from the superincumbent grits which form the dreary tract dividing the

drainage of the Dyfi from that of the Fyrnwy and Banw ;* and their relationship is further proved by the ores of lead and zinc being associated with the same minerals of baryta.

An essential difference is, however, to be remarked in the frequent intercalation of beds of felstone porphyry and gritty rocks of volcanic origin among the slates, a fact which bears in a marked manner on the distribution of the ores.

The most general strike of the lodes is E.N.E. and W.S.W., a direction so subject to frequent variations for small distances that some of the minor veins, if drawn in plan on a large scale, would appear to describe a zig-zag line ; such being particularly the case when the beds of rock frequently vary in their nature. Nearly all of the most productive deposits agree within a few degrees with this course, as Goginan, Daren, Cwm Symlog, Logaulas, &c. ; whilst among the exceptions Tre Taliessin, which runs N.W. and S.E., is said to have returned considerable quantities of lead ore, and the " Comet " lode at Cwm Ystwyth, coursing W.N.W. has, within the last few years, yielded several thousand tons, although only near its junction with the " main " lode, which points E.N.E. Variations to a less amount commonly occur, as evinced in the northerly turn of several of the lodes when entering the country E. of the Rheidol; and again on the outskirts of the main district, several lodes of minor importance, although yielding lead ore, exhibit a tendency to conform with the direction of the meridian, as Pant Mawr, and Siglenlas on the S.E., the lodes near Park Lodge on the north, and Rhysgog and others on the south.

The " underlie " or inclination is most frequently to the south, although it would appear to follow no rule, and in some important lodes, as the Esgair Hir, Daren, and Delife, it is to the north : the amount varies in general between 60° and 80° from the horizontal, excepting only in the remarkable case of the Comet lode at Cwm Ystwyth, which dips in many places at the low angles of 30° and 40°. The occasional flattening of the angle is not found in so marked a manner as in some mining districts to cause a diminution in the productiveness of the lode.

The filling matter of the mineral veins is principally slate rock, in angular fragments of all sizes, from the most minute particles so intimately mixed with the lead ore as to be only appreciable after the processes of *dressing*, to the large masses, sometimes fathoms in length and height, which, appearing to split the lode for a time in two limbs, are known as " horses " in Cornwall, and as " riders " in the north of

* In this district, also, a few metalliferous veins occur in the region of the arenaceous rocks alluded to, as at Moel Uchlas, near Can Office, and Bwlch Creolan, near Llangynnog ; but the trifling operations hitherto carried on upon them yield no data of importance.

England. Its most common associate is quartz, upon the tint and structure of which the miner builds his opinion of the hopefulness of the lode, drawing a wide distinction between the hard, massive, and opake siliceous matter, often forming irregular veins in the slate, and the drusy or cellular, or the granular, sometimes pulverulent "spar," which in most cases accompanies the metallic ores. The nature of this and other non-metallic members of the vein is also important for another reason, that upon their hardness and specific gravity, as compared with the ore, depends much of the economy in preparing the mineral for the market.

Calcareous spar, or carbonate of lime, occurs in smaller quantity, crystallized in large semi-transparent obtuse rhombohedra in the south lode of Logaulas; in considerable masses in some of the lodes of Copper-hill, and in the Estymteon lode opposite Dyffryn Castell, where, from an admixture with iron, probably also in the state of carbonate, it weathers to so dark a colour as to have been sometimes mistaken for zinc blende. In the bed of the river Ystwyth, at Pont Rhyd y Groes, is a vein of calc spar ten feet in width, corresponding apparently in its direction with the neighbouring lodes. At Hênfwlch it is met with in large ribs, and encloses spots of copper, lead, and zinc ores; whilst at Esgair Hir it occasionally plays the same part. In the Llechwedd ddu lode, Montgomeryshire, calc spar is also abundant, and crystallizes out in combinations of the prism and rhombohedron, sometimes very singularly grouped together: elsewhere it is occasionally seen, but not in quantity.

Fluor spar, so common an attendant of lead ores, is entirely unknown throughout the district.

Baryte, or sulphate of baryta, occurs in a vein of two fathoms in width at the surface, a few feet on the south of the lode of Bryn Dail, near Llanidloes; it is, as far as hitherto explored, very pure, containing but rarely a spot of metallic ore, and having only its joints slightly tinged by iron. It forms also a part of a vein in Cwm Mawr, two miles east of Llanidloes, and of those at Meifod and Llangynnog, in the north of the county.

Witherite, or carbonate of baryta, a mineral before supposed to occur only in three or four localities in England, accompanies in large masses the lead ore of the recently opened mine at Pen y Clyn, and exhibits in its druses well-defined crystals, formed by the combination of the rhomboidal prism with the double six-sided pyramid.

The same mineral may be found on the "burrows" of the Gorn mine, east of Llanidloes, where fragments of the vein prove it to have played the part usually taken by quartz, in cementing together the portions of rock and ore which with it constitute the lode. At Llan-

gynnog, as above mentioned, both the baryte and the witherite occur in the veins of Craig Rhiwarth and Cwm Orog; and it is remarkable, that whilst they are met with only in this eastermost zone of the district before us, the localities farther east, in which lower Silurian slates are exposed, as the Breidden hills and the Shelve country, offer those minerals, more particularly the baryte, in great abundance, as well in deposits almost *per se* as associated with ores of lead and zinc.

Of the metallic minerals, galena, or sulphuret of lead, in some cases pure, in others containing silver up to the proportion of 75 ozs. in the ton of lead, is the most abundant; it rarely in these counties occurs in perfectly solid masses, even as large as a cannon shot, the exceptions being Cwm Ystwyth, Pen y Clyn, and Llangynnog: elsewhere the low specific gravity proves it to contain some foreign substance, although frequently in particles as small as the finest sand. Galena is met with in several of the mines crystallized either in the cube or octahedron, or in a combination of the two forms; and the argentiferous variety, as at Cwm Sebon, is quite as often well crystallized as the non-argentiferous ore of Cwm Ystwyth.

White-lead ore (the carbonate) is found in a few of the lodes, particularly near the surface, but not in great quantity, and only in consequence of the decomposition effected by the infiltration of water holding carbonic acid.

Green-lead ore, or pyromorphite (the phosphate), occasionally tinges with a coating of microscopic crystals some of the stones thrown out on the surface of the mine, where the galena has been exposed to the action of some decomposing organic matter, and has parted with its sulphur to obtain phosphoric acid. Zinc blende, the " black jack" of the miners, is almost equally abundant with the galena, and in many places even more so, being in thin strings and small spots the most frequent ore of the poorer lodes; but it occurs only at two or three mines in sufficiently large masses to render it at the present low price worth the expense of separation and carriage. Calamine, the siliceous species, has occurred in considerable quantity at Nant y Creiau mine, below the adit level, but has been thrown away as a worthless " spar:" elsewhere it may occasionally be seen investing blende with a thin crust.

Copper pyrites, in irregular spots, is often mixed with the galena, sometimes in sufficient quantity to repay the labour of separate dressing; it is said to have been found more abundantly in some veins near the surface than at greater depth, but there is no great difference to be remarked. In a lode which crosses the main road at Tre'rddol it occurs without any associate, and of excellent quality: in the vein of

Cwm Rhicet, above Llanidloes, which runs for some distance in the bed of the Severn, it is also alone, but not very abundant.

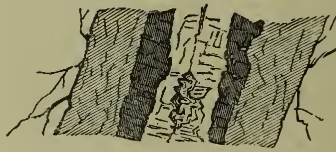
Iron pyrites, or sulphuret of iron, sometimes sprinkled in cubes in the slate rocks, is not found abundantly in this district, the only exceptions being the "Comet" lode (Cwm Ystwyth); the Estymteon, where it forms a considerable rib of a granular easily decomposing variety; and the lode at Cam Dwr; whilst at Nant y Creiau and Esgair-lly, the prismatic species occurs in crystals which have a tendency to dispose themselves in stellated groups.

Siderite, or carbonate of iron, occurs in cracks in the slaty rocks near some of the lodes, as at Daren; and in their mass, accompanying carbonate of lime, as at Hênfwlch, and in the Estymteon lode.

An ore of manganese has been extracted from the old levels on the hill of Drosgol, near the Rheidol, and may be found near Pen y Castell, farther west on the same lode; it is, however, the Psilomelane, a hydrous ore combined with a base, and easily distinguishable by its superior hardness from pyrolusite, the profitable ore of manganese.

Such being the substances which fill the veins, we find them very rarely disposed with so great regularity as to lead to the conclusion that the deposition of any one substance ceased before that of the other commenced, as may sometimes be inferred elsewhere;* on the contrary, they occur in strings and spots, sometimes parallel for small distances, but more commonly ramifying irregularly, and often forming a perfect net-work. Generally, however, we may observe, that the calc spar takes the inner side of the quartz, whether in drusy cavities or in ribs; and it would appear that the galena occupies an analogous position with regard to the zinc blende, a point of great importance as bearing on the theory of these mineral veins, and its future application to mining. This relation is exhibited in the lode of Nant y Creiau, which generally assumes the banded character of the diagram,—

Fig. 1.



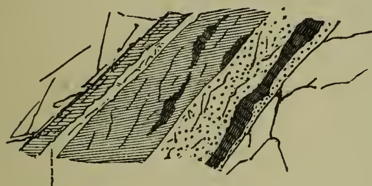
a *b* *c* *c* *b* *a*

a Zinc blende. *b* Galena. *c* Quartz.

* See, for examples of such relations in our southern counties, De la Beche, Geological Report on Cornwall and Devon, 1839; and Robert Were Fox, Report of the Royal Cornwall Polytechnic Society for 1836. For those of Saxony, Werner's Neue Theorie der Gänge, and Freiesleben's Oryktognostiche Schriften.

A structure of the same order, but varying constantly in its details, is exhibited by the Estymteon lode in the Tyn-y-fron level.

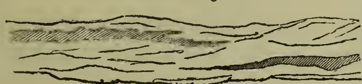
Fig. 2.



a Copper Pyrites. *b* Quartz. *c* Zinc blende. *d* Iron Pyrites. *e* Galena.

When the mineral deposit is of considerable width, the orey portion has often a tendency to run in irregular sheets, sometimes near the "lying," at others near the "hanging wall;" and where one such stripe has been followed till it seems to have wedged out, the commencement of a second has been found by turning away towards the opposite side: the following wood-cut exhibits a "splice" of this kind, *a* and *b* being the metalliferous portions of the whole width *c d*.

Fig. 3.

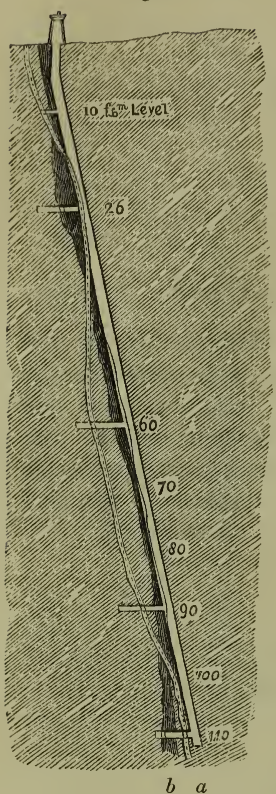


The structure, however, which is most characteristic of the lodes of these counties, and in which they differ from the quartz veins frequently interposed between the planes of the slaty beds, is the brecciated; in some cases angular fragments of slate are set in a paste of quartz, in others cemented by galena, or by zinc blende, whilst more rarely, as at Hênfwlch, a ground mass of calc spar incloses angular lumps of galena, of copper pyrites, and of zinc blende.

Although, as has before been remarked, it does not appear that the lodes of this district can be referred to different epochs, there is evidence that subsequent to the filling of certain of the fissures, fresh disturbances have given rise to new cracks coincident, or nearly so, with the original direction. The banded structure of such veins as the Estymteon and Nant-y-Creiau, may be partly referred to such action, as also the occasional frequency of slickensides both on the well-defined walls and in the interior of the lodes, besides the angular fragments of metallic minerals in the breccias above-mentioned; but at Goginan the greater extent of the workings presents us with a more satisfactory proof.

The productive lode is there accompanied by the "soft" or "north" lode, which after being first met with, as its name implies, on the north wall, has since been proved to cut through its neighbour, both on the line of horizontal bearing and of inclination; its width of 6 inches to 4 feet, is filled with fragmentary and triturated slate rock, occasionally seamed by threads of calc spar, and sometimes containing, near its junction with the other vein, isolated lumps of lead ore. The accompanying diagram exhibits the relations of the two lodes on the dip, at Taylor's shaft; and they are, on this account, important, because the nature of the two not being held sufficiently distinct, it was feared, when the shaft reached 100 fathoms in depth, that the ore had died away; and it was only at 110 fathoms that a cross-cut to the north proved the fact of the soft vein having cut through the other, and thus presented itself first, although behind it remained the true lode in undiminished width.

Fig. 4.



a North, or soft lode.
b Principal lode.

At Cwm Ystwyth, a similar fissure, of larger dimensions, bearing nearly east and west, has interrupted the principal lodes, and, being probably accompanied by a considerable dislocation, has left them without any apparent continuation on its south side. The lower "adit levels," or water galleries, have passed through a width of 20 fathoms, generally occupied by disintegrated slate rock, although in some places (as in Gill's lower level, and in the new shaft, at 16 fathoms below the adit) it is filled with water-worn pebbles, often of large size, of hard slate and sandstone, very similar to some which may now be picked up in the bed of the Ystwyth.* The phenomenon, however, has resulted from no

* In the old open workings at Copper Hill, Cwm Ystwyth, a number of hard ellipsoidal stones may be found, which have clearly at an early period been used as mining tools. Most of them are considerably worn at one end, and some are marked by a rough groove round the middle, by which they seem to have been fastened to a handle. There is little doubt that they belong to a time when iron was quite or almost unknown:—

"Arma antiqua manus, ungues dentesque fuerunt
Et lapides."—Lucret.

And when, as in the arrow-head described by Herodotus—

"ἀντὶ σιδήρου ἐπῆν λίθος."

such superficial cause as a change in the bed of the river, for the point where the rolled pebbles were found in the shaft must be 80 or 90 *feet deeper than the adjoining bed of the Ystwyth*, in which the solid rock appears; and the same "soft ground" of equal width, although without pebbles, whilst it has obstructed the course of the 30-fathom level, which is again considerably deeper, has also been pierced on the west by day levels, at a great height above the valley. The deposit of lead ore, so highly productive within the last few years, which was formed by the junction of the "main" with the "Comet" lode on their underlie, began to lessen its inclination as it neared the "soft ground," till at length it was worked over a large area inclined at an angle of only 8 or 10 degrees. The moment, however, that it touched the broken slate it dwindled rapidly away, and was soon altogether lost; and it is quite consistent with probability that the rock near the wall of such a fissure would be so broken as to disorder the regularity of the lode, even before it were entirely cut off. The fragmentary matter itself occasionally contains threads of calc spar, but, as far as yet known, nothing like a true vein; and it becomes an interesting problem to determine whether this should be considered the true boundary of the ore, or whether it is not rather a subsequently formed cross course which has either raised or dropped the lode on its other side. Unfortunately, the small extent of the workings, and the indistinctness of the walls or sides, leave the miner, for the present, without the criterion which a knowledge of its inclination would afford him.

These appearances, as far as yet known, are exhibited in the sections attached to the plan of the Cwm Ystwyth mines. (Plate 11.)

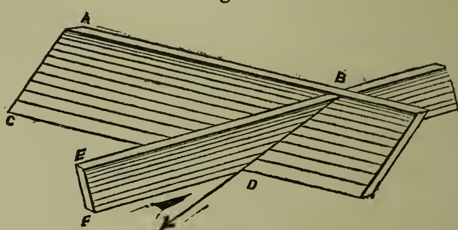
"Slides," or cross fissures of small dimensions, generally filled with clay, or sometimes appearing as a mere parting in the rock, are not unfrequent, and in many cases dislocate the lodes a few feet, as at Cwm Ystwyth, the Bog Mine, Gwaith goch, Geulan, &c.; they are, however, less common than in most mining districts. The lodes themselves appear, in many cases, to be accompanied by a similar relative up-and-down throw of the rock, or "country," on their opposite sides; but, from the absence of easily-recognized beds, it is difficult to measure, or even to mark, any change of level which may have been effected.

With regard to the ore-bearing portions of the lodes, several facts have been observed which are in perfect accordance with the experiences of other districts. When two lodes approach each other under a small angle, the junction is nearly always marked by a larger deposit of ore;* and the same effect is produced when branches or shorter veins

* It must be understood that this observation has no reference to veins of purely mechanical origin, as, for instance, the "soft lode" at Goginan; for the junction of such with

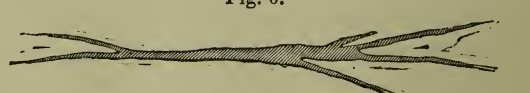
fall in with the principal lode, whether on the line of strike or on the dip: the only case which I heard of to the contrary is, the junction of the Llechwedd-ddu and Esgair Galed lodes, in Montgomeryshire, where no such enriching has taken place. Should the productive ground not extend in length, or the lodes meet at a more obtuse angle, it is often found that the deposit of ore follows the line of intersection of the two planes, and therefore varies with their course and dip. One of the most striking instances of these relations, from the large quantity of ore with which it was accompanied, is afforded by the junction of the "Comet" and "Main" lodes, at Cwm Ystwyth. Let portions of the two planes be represented in plan, for the same vertical depth (as 20 fathoms), by ABCD, for the Comet lode, and EBFD for the Main lode; then the line BD, or the intersection of the two planes, gives the direction of the great deposit of ore, which was always found, at any given level, to diminish rapidly to the westward.

Fig. 5.



The same result is also observed, and perhaps in a still greater degree, where several lodes have united in one, as represented in the diagram, fig. 6:

Fig. 6.



instances of which occur at Fron Goch, at Esgair y Mwyn, and at Goginan, in each of which the principal operations have been conducted in the part where all the veins are combined.

In many cases, the productive portions are observed to be more continuous in a vertical than in a horizontal range, and to incline somewhat westward in their descent. It might sometimes be inferred from this appearance that the "shoots" of ore, as they are termed by the miner, run parallel to the beds of rock, and thus accompany those strata

other veins is not thus characterized, as has continually been proved at the same mine, and might indeed be predicted from consideration of the very different mode in which they must have been filled.

whose composition has been most favourable to the deposition of metallic matter; but the fact is far from being generally established, and they would appear rather to conform with the dip of the planes of cleavage, if we look at the persistence of the westerly dip, in some instances, where the beds are inclined in the opposite direction.

The lead veins of this part of Wales differ from their congeners in Cornwall in one point, upon which all the miners are agreed, viz., that when they pass from a harder to a softer rock, their mineral contents decrease.* The actual following of the vein in a level certainly proves to be an index to the rock which it traverses, for, as soon as it diminishes in size, and is filled with soft argillaceous matter, the adjacent rock is invariably found to have degenerated to a shaly character. In Cwm Symlog, some bands of fissile slate, which, at the surface, resist decomposition and degradation better than the more massive beds, are traversed by the lode, and exhibit this result very distinctly; in the more productive parts of the mine, the rock, as in all the Goginan district, is so solid that its bedding would often be undistinguishable but for the stripes of a darker colour which here and there relieve its pale gray tint; but where the lode passes into the "cross measures," as they are termed, of slate, not a vestige of ore remains to tempt the miner onwards.

II. — *Considerations on the Practical Working of the Mines.*

Among the numerous deposits of ore in Cardiganshire and Montgomeryshire,† some have been worked at periods so early that the date is lost in obscurity, and yet they are probably far from being exhausted. Others have yielded, two centuries ago, enormous wealth to a few individuals, and have been, nevertheless, almost buried in oblivion till

* At the exceedingly productive mine of East Huel Rose, in Cornwall, not only is the "Killas" very soft, but the lode itself, including its saccharoid quartz or "sugary spar," is in so disintegrated a condition, that a blow with the pick will often cause it to run down like a quantity of sand and mud.

† At many points of these mines the attention of the antiquary might be arrested by the term "Roman level," applied to certain galleries of small dimensions, in which the rock has evidently been hewn by tools, not blasted with gunpowder; but it is hardly necessary to observe that the retailers of tradition who here ascribe to the Romans, as do the eastern Irish to the Danes, all works of more than a few generations in age, overlook the fact, that it is little more than two centuries since gunpowder was generally introduced in mining, and that all subterraneous operations, up to the period even of Sir Hugh Myddelton's successful adventures, were effected by means of the hammer and "gad," or miner's wedge (*Schlägel und Eisen*). At Cwm Symlog and Esgair-hir, two of the most noted mines of the 17th century, some of the tools have been discovered, amid the refuse left by "the old man;" and, as may be seen in the specimens preserved in the Museum of Practical Geology, they correspond exactly in form with those used in the German mines at the present day, whilst they differ from those employed in Cornwall, the only British district in which the miners are skilled in this mode of "breaking ground."

within the last few years; whilst, of those which are now in activity, some of the most productive have been re-opened by mere accident, and others, often bearing a promising appearance, continue to languish on, without fulfilling the hopes of the adventurers. Mining, it is true, is proverbially a speculative undertaking; but a few reflections on the spirit, as well as the actual mode, in which the works are carried out, may show that whilst, on the one hand, a certain judicious application of the means to the end is necessary to a successful result, on the other much may be expected from enlarged general views and from the daily increasing effect of Science on the advancement of Art.

The principal features of the exploitation are very similar to those which are met with in our southern counties, as we might expect from the fact of most of the captains or superintendents being Cornishmen. Under favourable circumstances, shafts are sunk on the course of the lode, at convenient distances, connected by galleries, or "levels," at every 10 fathoms in depth,* besides which short underground shafts or "winzes" communicate here and there from one level to another, and the orey mass is thus subdivided into quadrangular portions of convenient dimensions. The valuable part is then "broken" by "overhand stopeing," or a series of reversed steps, where the "attle," or rubbish, is thrown underfoot; whilst the miners thus rise from a lower to a higher "level," extracting, as they proceed, all the "orey ground." It is manifest, however, that by this method a certain degree of expensive preparation must precede the profitable extraction of ore; and we find that, in too many cases, either from want of sufficient means or knowledge, these preparatory operations are neglected, the seizure of the orey points made the first object, and a mine, which might in better hands prove a lasting source of profit, is for a while forced to yield more or less of its treasures at greater comparative expense, and is eventually crippled, abandoned, and left with a bad name to deter future speculators, or, at all events, in such a state as to require, on their part, a great outlay to restore it to a favourable condition.

The district before us has, however, as compared with Cornwall, the great advantage of being so diversified with hill and dale, that a large proportion of the expensive shafts may be dispensed with, and the facilities for driving an adit level or water gallery often supersede the necessity of raising the water by machinery for many fathoms in height. Moreover, the subterranean springs are not abundant, probably in con-

* Considering the irregularity of the lodes, and the inferior value of lead to copper ores, it may be suggested that the Cornish rule, of driving levels at every ten fathoms, would be advantageously replaced by the Saxon method, of placing them at 20 fathoms asunder; for, if we consider the greater persistence of bunches of ore in a vertical than in a horizontal range, the ground would be almost as efficiently proved, whilst the expenses of driving would be materially diminished.

sequence of the ready efflux afforded to the surface water by the numerous valleys; and in most cases an overshot wheel of 30 or 40 feet diameter, working pumps of six or eight inches calibre, is found to be sufficiently powerful. The obvious economy of water power has led to a continually increasing care in the means of obtaining it; and not only have streams been conducted for several miles along the mountain side to assist in expelling the waters from the depths of the mine, but large reservoirs have been constructed in the main ridge, and natural lakes, as the Teifi pools, have been made instrumental to the same purpose. It has thus come to pass, that notwithstanding the natural, though sometimes misplaced, predilection of the Cornish miner for steam, not a single steam-engine is at work within these counties, excepting a small one used for drawing the ores, at Llangynnog. The water-wheels chiefly in favour at the larger mines are constructed with axles of wrought iron, socket rings for the arms, and rim of iron; and the arms (simple radii), buckets and backing of wood, a combination which gives great lightness and elegance to their appearance, and acts excellently in the working.

The details of the timbering of the shafts and levels are similar to those of Cornwall and Devon, whilst walling or dry masonry is very little practised; and yet, where the neighbouring stone is applicable, it would often be found serviceable for works intended to stand for many years. A striking difference may be remarked between the condition of an abandoned adit-level in the Welsh hills and that of one in some of the continental districts, where more attention is paid to this point; in the former case, scarcely a season elapses before the mouth is closed in a heap of ruin, whilst in the latter, even after several years, the entrance remains practicable.

For the conveyance of the ore and stone, subterranean tramways are in some cases laid down, but in general no other means than a wheel-barrow is used, even for distances of 50 or 60 fathoms, and along the uneven rock floor of the level. The raising in the shaft is effected in a "kibble" of sheet iron, without guides of any kind, however inclined the shaft may be; and it is only at Goginan and Llangynnog that for this rude method have been substituted inclined planes, with a double line of rails. Single-link chains and hempen ropes alone are in use, for the wire ropes supplied for trial in a few cases by the manufacturers were not of a construction adapted to mining purposes, and have only given rise to a prejudice against what is in truth one of the greatest improvements in the material of mines.

We may not, however, enter farther at present upon minutiæ which vary at different places with the skill of the superintendent and work-

men, but proceed to a few general considerations affecting the present condition of some of the mines.

There may doubtless be found in the history of mining, instances of immensely rich deposits having been won after little or no original outlay; but it is hardly necessary to premise, that in the ordinary course of events the opening of a mine can only be effected by the employment of a certain amount of capital, increasing with the magnitude of the operations. When the first preparation has been effected, it is still necessary to proceed with caution; we see that access is obtained to a mass of ore of no value so long as it lies in the depth of the earth, but obtaining its full price when once transferred thence into the hands of commerce; and we may liken it in this condition to a sum of money hoarded up uselessly and returning no interest; nor would the mere man of business hesitate to think that the whole should be realised with the utmost rapidity, and that every year, nay month and day for which it remained concealed in the mine, were so much interest lost or money squandered. But in the art of mining, various elements enter into the calculation which, though they allow the truth of the above view to a certain extent, set a decided limit to the rate of extraction. Thus, the number of men and machines which can efficaciously be brought to bear on a given space, has its maximum which cannot without detriment be overstepped; and again, the principle, always adhered to in legitimate mining, of keeping works of preparation in advance of those of extraction, renders it necessary not to allow the latter to be unduly hurried forward. On the other hand it has often appeared feasible to individuals or companies with small resources to commence operations on a diminutive scale, and with the proceeds gradually obtained from the sale of their ores, to enlarge their plans from time to time, till they shall at length stand on the same footing as if they had begun with a large capital. Seldom, indeed, is this hope fulfilled. The manifold incidental and unexpected charges, and the uncertain continuity of the ore deposit often withhold for years the power of increasing the scale of works; and in the meanwhile, the mineral which is raising, and which if more vigorously plied would yield a profit, is either barely paying more than its own costs, or is perhaps entailing an annual loss hardly sufficient in magnitude to deter the speculator from proceeding. Here, then, we have two extremes, the pillaging, and the sluggish extraction of ore, which must equally be avoided, and between which the "golden mean," depending on many various conditions, can only be selected by a manager who unites to a knowledge of the details of the art, a general acquaintance with the principles of commerce and social economy.

Among the mines enumerated in this paper, we may trace a variety

of courses steered between the Scylla and the Charybdis of the unskilled agent; some of the adventures are dragging on amid shoals, though it were well by a vigorous effort to prove them worthy either to be better conducted or to be abandoned; others, in spite of mere empirical direction, have floated into the middle of the stream; some, though launched boldly, have after a while, from want of power, drifted among the rocks, whilst a few, though agitated by the numerous disturbances inseparable from the nature of the undertaking, succeed in holding on their prosperous way, and reward the conductors for their spirit and judgment.

Numerous considerations tend to encourage the development of the mineral resources of this district, the great number of lodes lying idle, or only in some cases tried to a small depth; the probability of the existence of many more, considering how difficult from the nature of their composition is their discovery at the surface; the facility of drainage; and last, though not least, the fact of the resumption of the two most profitable mines having resulted from very fortuitous circumstances.

The mine of Logaulas had long been worked by shallow shafts with various success, till the adventurer, resolving to make a bold push at a greater depth, commenced, towards the close of the last century, to drive an adit-level from the north, which after a course of nearly half a mile should reach the lode at a depth of 60 fathoms from the surface. The rock was hard and the progress slow, but for upwards of 30 years did the miners persevere, till at length, after piercing about 360 fathoms, a lode was cut; but so miserable was the aspect it presented, that after driving right and left upon it for a few feet, the disappointed speculator gave up all his cherished hopes and abandoned the undertaking. After a short interval some Cornish adventurers were led to believe that something yet remained to be done, and having set a party of men to push forward the same level, in the course *of a few feet* cut the true lode, in the midst of a vast deposit of ore which yielded rich returns for several years. This company, however, in their turn, fell into a similar error, and losing the true lode, mistook for it a small vein on the south, dispirited with whose poverty they surrendered the mine. The present holders, after making an accurate survey, were satisfied that they must be too far southward, drove a "cross-cut" towards the north, and very shortly discovered not only the lode, but a rich "bunch" of ore, parallel to which their predecessors had been toiling for many a fathom through barren rock at the distance of only a few feet. The mine has ever since been yielding several thousands of pounds profit per annum.

Still more hopeless appeared to be the condition of Goginan, when taken in hand by the Messrs. Taylor and Company. The previous adventurer,

whose excavations extended to a depth of 30 to 40 fathoms, repeatedly assured them that it was in vain to expect anything there, for that after many years' experience he was so satisfied that no more ore remained in the lode, that he would undertake to carry on his back to Aberystwyth all that they would ever extract. And yet, in spite of predictions, the mine has for years produced upwards of 1500 tons of silver-lead ore per annum.

Among the miners of this part of Wales, a prejudice, somewhat modified of late, by the example of the above mines, is prevalent, that lead ore is not continuous in depth, and that 30, 40, or 50 fathoms is the limit below which it will not extend; and, in support of the argument, they adduce instances of lodes several fathoms wide at the surface, which at 40 fathoms have dwindled away to a few feet, as Esgair-hir; and of others which, very productive in the shallow workings, have presented a mere thread, when opened at greater depth, as at Tal-y-bont.* We might at once give credence to such an opinion, did the geological features of this district resemble those of Durham, of Derbyshire, or Flintshire, where the ore-bearing strata are of known and moderate thickness; but with the deep clay-slates of the lower Silurian and Cambrian systems, the same reasoning will not hold; and cases such as those above cited may probably be explained by a local change in the character of the rock, or, in fact, are to be classed among those "nips" or "squeezes" (*étranglements*) to which all lodes are more or less subject, both in their strike and dip. How rarely has a vein been systematically opened, as in Cornwall or in Saxony, to a depth of 200 or more fathoms, without several of these interruptions to its thickness; and how common to see a lode of six feet wide, after being reduced to a mere riband for a considerable distance, open again to its former size!

That lead ore is not more contracted in its vertical range, *cæteris paribus*, than copper, appears to be satisfactorily proved in districts where due perseverance has been applied. In the Hartz, many of the mines are from 200 to 300 fathoms deep; at Andreasberg, in the same mountains, the vein of the Sampson Shaft is still productive at 410 fathoms from the surface. Around Freiberg, in Saxony, most of the mines are from 150 to 250 fathoms in depth, and the lodes continue

* It has been asserted of the great vein at Llangynnog (Williams, Mineral Kingdom, 1789), that it is at a certain depth entirely cut off by the schist underlying the massive beds of gray felspathic porphyry in which it had been so productive. Such, however, in one level after another, is proved to be untrue; for although no ore deserving of mention has been found below the horizon where the bluish slate clay was first encountered, the lode is still well-defined, and filled, for a width of one or two feet, with shaly rubbish, to a depth of 50 fathoms lower; and there is every reason to believe that, should it enter a second intercalated bed of porphyry, it would again increase its dimensions and its store of valuable mineral.

downwards with undiminished thickness,* the principal falling off being in the proportion of silver.

At Przibram in Bohemia, the richest silver-lead mines of the present day in Europe are worked at various depths extending to 200 fathoms; the lodes occur, moreover, in clay slate, probably of the lower Silurian period; and, since they *never yield lead ores shallower than 40 fathoms* from the surface, were, during a long period, not suspected of containing anything more than brown iron ore (the "gossan"), which was raised for the neighbouring furnaces. The only two mines in Cardiganshire which have attained a considerable depth, Logaulas and Goginan, have well rewarded the attempt to break through prejudice, the lodes being, at the respective depths of 105 and 110 fathoms, as large as in many of their most favoured spots above.

With respect to the rapid termination of mineral veins in depth, Baron von Beust † observes, that it is a view which would never enter the mind of those who have studied the subject in a lofty mountain range, where Nature displays such convincing sections, as chase away the petty ideas amid which, in a tamer country, fancy may lose itself. Few could hesitate to ascribe the phenomena of lodes to some cause too deeply seated to cease its action at a few fathoms in depth, who had seen a grand natural profile like that of the Grand Clos near La Grave, between Bourg d'Oysans and Briançon, in the Department des Hautes Alpes.

From the valley of the Romanche, the mountain on the left hand towers boldly four or five thousand feet, to a height covered with glaciers, whilst the bare rock of this stupendous face is obscured only at the base for a few hundred feet high by the detritus hurried down by avalanches.

Above this talus a mineral vein, called Fécheronde, may be seen to rear itself unbroken to the lofty elevation where it is concealed by perpetual ice; its width is but 10 inches to 3 feet, and when the average is taken, is totally independent of the depth below the surface of the mountain; whilst the ores which it contains, galena, with traces of copper and iron pyrites, appear quite as much developed at the lower as at the upper visible extremity, though they are not sufficiently abundant to encourage the prosecution of the works which have been commenced at various levels.

On the opposite side of the valley, two other lodes, called Pissenoire and Javanelle, are similarly displayed in a section of gneiss rock, which rises to a height of 1800 feet above the valley.

How insignificant after this do mining trials appear which, after

* See Von Herder's work, "Der tiefe Meissner Erbstolln," p. 21.

† Kritische Beleuchtung der Wernerschen Gangtheorie, Freiberg, 1840.

penetrating some 40 or 50 fathoms, have been abandoned, because a diminution of size or contents led to the hypothesis that the lode was drawing to a termination!

The "dressing" or preparation of the ores for the smelting furnace is a division of the practical department which deserves considerable attention, both from its economical importance, and from its varied, though far from perfect, application of hydraulic principles. It is a series of processes adopted for all the metallic minerals, but in a very different measure, according to the following conditions: first, whether the ore is by nature pure or mixed with other substances; secondly, as it is more or less valuable with reference to the expense of the operations; and thirdly, according as it must, to suit the existing methods of smelting, be brought to a higher or lower per centage of metal; and there is a limit, varying with these circumstances and the local questions of cost of power and labour, below which the working of poor ores ceases to be remunerative.

Now the dressing at some of the mines in Cardiganshire is carried to a greater degree of nicety than we meet elsewhere in the kingdom, because, 1st, the ore is much more intimately mixed with other matters than the galena of our limestone, granite, or Devonian slate districts; 2ndly, it is argentiferous, and therefore for a given weight more valuable; and, 3rdly, it must be "brought up" to about 75 per cent. of metal, whilst the ores of copper, as taken by the smelter, average only a per centage of from 4 to 20; and on this account it will be desirable to enter so far into the details as to exhibit the sequence of the operations, and the apparatus by means of which they are carried out.

The vein-stuff in large fragments, as extracted from the mine, requires, besides the washing away of the finer matter in water, such as clay, &c., a variety of treatment which may be referred, in general, to two heads; viz.:—

1st, *reduction* to a small size,
2ndly, *separation*, of the ore from the refuse.

At the smaller mines, and particularly at those where the ores contain no silver, the means applied are simple; but since they require a large amount of manual labour, are inefficient, very costly, and must necessarily leave a great portion of the poorer materials unworked.

In such cases, the coarse vein-stuff is broken by hand with an iron mallet of peculiar form, called a "bucker," to the size of nuts, or smaller, if the nature of the stone require it, whilst the pure portions are picked out by themselves, and those containing very little or no ore, are thrown away. The mixed ore requiring *separation*, is then

"jigged" in a machine known under various modifications in all mining districts. In a strong rectangular chest containing water, a tray whose bottom is composed of iron or brass wire meshes is suspended in such a manner, that by the action of a lever it may be depressed in the water with a jerk acting through an inch or two vertically. When the broken ore is placed in small quantities in the sieve, and subjected to such an action, the particles are all momentarily raised by the resistance of the water; and the heavier being the first to settle, there is soon effected a separation into three parts,—1st, the "bed," the pure ore, which by its greater specific gravity occupies the lower part; 2nd, the mixed ore and stone, called "raggings," which may be worthy of a second treatment; and 3rd, at the top, the worthless spar and slate, "toppings" or "skimpings," which is scraped off and thrown away.

A fourth sort is obtained from the smaller grains which fall through the sieve, and are left to accumulate in the chest or "hutch;" and this "hutch-work," owing to the very cleavable or the granular structure of the galena, is almost pure. The resulting products are washed in a "strake" (fig. 5), (*Pl.* 13,) an inclined trough with a considerable stream of water flowing through it; and are completed by cleansing on the "flat buddle" (fig. 6), (*Pl.* 13,) a modification of the inclined plane peculiar to the Welsh lead mines, and differing from all others in its great proportional breadth, as well as its very trifling inclination. The ore or "work" is placed in a small heap on one side of the supply of water, and drawn with a hoe partly against and partly across the stream to the other side of the buddle, losing in its passage all the specifically lighter parts. Even when a heap of ore would appear pure to the casual observer, its treatment on the flat buddle will relieve it of a portion of blende and pyrites, minerals, which from their high specific gravity may in small quantities have resisted the previous operations.

At the more extensive mines a great portion of this manual labour is superseded by machinery; and for the purpose of turning to account the poorer mixtures, a variety of apparatus is employed, according to the judgment of the local managers; but we cannot err in taking Goginan mine as that in which such processes are conducted on the largest scale, and with the greatest degree of neatness and precision; nor can we here omit to acknowledge that the survey is much indebted to the Messrs. Taylor, so deservedly known in connexion with the mining interests of the country; to Mr. Fossett of Aberystwith, and to their agents, for the readiness with which they furthered the objects of inquiry.*

* It would be invidious to particularise the agents at any one mine, since the Survey met with cordial co-operation on the part of all the mining captains in both counties.

In plate 12, will be found a roughly-sketched ground plan of the dressing-floors of Goginan mine, by aid of which it will be easy to follow the ore in its various stages from its first appearance at the surface, to the state in which it is forwarded to the smelter.

The lode at this mine is, as we have above seen, occasionally very large, but the ore is distributed so irregularly throughout, that the whole mass must be extracted, and consequently no separation is required under ground. From the mouth of the incline, where it first sees daylight, it is brought by a tram waggon and thrown into the "passes," large stone-lined receivers with their floor sloping towards an orifice through which the stones, aided by a small stream of water, slide gradually to the grate and picking table, where they are received by a group of workpeople, chiefly boys and girls; and whilst the large lumps are broken up with a "spalling sledge," the smaller ones are arranged according to size, by passing through a cylindrical griddle revolving by water power, and undergo a certain sorting, as to quality, in order that the richer parts may be exempted from some of the processes necessary for the poorer. The broken stuff is now conveyed to the "crusher," a pair of strong cast-iron rollers driven by a large water-wheel, and revolving in opposite directions, and is reduced to grains capable of passing through a sieve of six holes to the linear inch. It is unnecessary to say more of a machine so well known as the "crushing mill," except that in Cardiganshire it differs from those employed in its birth-place—the north of England, in possessing but one pair of rolls instead of three, and that pair of greater diameter, ranging between 20 and 30 inches: the construction is thus simpler, and those who test their work aver that when carefully fed, this crusher is more efficacious, if not generally, at all events for the veinstone of the slaty rocks.

We have now (setting aside perhaps some of the richest, as pure, and the poorest, for the "stamps,") the great bulk of the ore reduced to a heap of grains and powder, which as fast as it falls from the sieve attached to the crusher, is swept away by a stream of water, and deposited in a "tye," (fig. 4), *(Pl. 13)* where the heavier and coarser particles will rest in the "cofer" or upper division; whilst the lighter will be carried to the lower part or body of the tye; and both sorts are constantly shovelled out in separate heaps, to make room for fresh accessions. This is the first point of a long series of divisions and subdivisions, selections and rejections, which to follow out to its extremes, varying as it does with many conditions, is impossible, except in practice.

The two sorts are at present the rough (A), and the fine (B).

(A) is now treated at the jigging machines (*e*, *Pl.* 12) in sieves of five holes to the linear inch, where it yields :—

1st, (a), "Hutch-work," or the finer part which falls through the sieve, and is afterwards washed in a strake (fig. 5), and divided into . . . . . .
- (α), The "rough," or coarser part, treated and subdivided in the jigging machines, near the lower crusher.
- (β), The "middle" and "tails," or finer part, sent to the "round buddle" (fig. 1, pl. 13).

2nd, (b), "Bed," which, being nearly "clean," is finished in the flat buddle (fig. 6).
3rd, (c), "Ragging," re-jigged once or twice, and re-divided according to circumstances
4th, (d), "Skimpings," thrown away as useless.

(B) is treated in the round buddle (*Pl.* 13, fig. 1), to which (B) is also destined : this machine, tried many years ago in Cornwall, although at present peculiar, it would seem, to Cardiganshire, separates the particles of unequal specific gravity on a circular space considerably inclined from the centre towards the circumference. Its construction will be seen from Pl. 13 (figs. 1, 2, and 3). (*a*) is a box or "cofer" where the ore or slime mingled with water is thoroughly worked up by the "tormentor," a cylinder of wood instructed with iron knives, which revolves on the same shaft as (*b*), a sieve serving the purpose of rejecting pieces of wood or hard lumps into the board (*c*) ; the orey mud is delivered by the launder (*c d*) into a funnel (*d e*), which is kept in revolution by a miniature water-wheel acting through bevelled gear, and whence, trickling down the sides of the fixed cone (*e f*), it commences to flow off radially towards the circumference, leaving by degrees the heavier constituents in its downward progress, whilst the surface is swept smooth and the action equalized by the laths (*l l*), suspended by strings from the cross rod (*k k*), which revolves with the funnel and vertical shaft ; so that the mixtures of different per centage will be arranged in concentric circles. A material which contains $\frac{20}{100}$ of lead may by this process so get rid of its impurities, as to rise to $\frac{60}{100}$; and the rapidity of action is so great, that each round buddle can work up in a day 12 tons, although a large portion of this quantity must again be subjected to the same operation.

(B) is thus divided by the round buddle into—

(a), "Heads," sometimes re-buddled by itself, and re-divided, or worked in the "dolly-tub ;" where the deposits are as follows . . . .
- (α), Top layer, 1 inch thick, containing about 1 in 40 of lead, treated in the "tail buddles."
- (β), Still very poor, re-worked in the round buddles.
- (γ), A layer which is "re-dollied."
- (δ), The bottom, which is "clean" ore.

(b), "Middles," again worked in the round buddle, and re-divided.
(c), "Tails," thrown away as worthless.

The "dolly tubs" and common buddles need no particular descrip-

tion, being similar to those employed in other mining districts of England.

The water employed in these various operations carries off, in mechanical suspension, a large amount of extremely minute particles; and is led into a series of "slime pits," or rectangular tanks, where its velocity being checked, it may throw down a sediment ("the slime"), to be afterwards treated with similar products resulting from the stamps.

The poorer ores, hitherto left unnoticed, are fragments of slate, quartz, or other vein-stone, containing spots or fine threads of galena, which no breaking by hand or by the crusher would sufficiently lay open. These, as well as the "raggings" from the western "jigging hutches," are pounded up in the upper and middle "stamps;" and the produce, after being caught in a "pit," is washed through a "strake," and the coarser part afterwards treated in a "tye."

Of the stamps it is only necessary here to state, that they are constructed on the Cornish model, where the produce escapes by small gratings or perforated plates from the front and both ends of the "cofer:" in the newest erected set, the "head" of cast-iron, weighs 260 to 280 lbs., and the wooden "lifter" 2 cwts., or, together, nearly 4½ cwts.; the lift is 8 inches, and, when going at the most advantageous speed, each stamper makes 54 blows per minute, or 4 to each revolution of the axis; whilst the water-wheel (of 37 feet diameter) revolves 4½ times per minute, and the axis or barrel three times as fast.* The *rationale* of the stamping process is not so simple as at first sight it may appear; and many of its particulars, as the form of the "cofer," mode of exit for the "stuff," weight and rapidity of the stampers, and

* During my residence at Schemnitz, in Hungary, experiments on the dressing of ores were instituted, from which, among others, the following useful results were elicited. It must be premised that the ores were chiefly hard auriferous gangues, and that from the mode of outlet from the "cofer" adopted where gold is to be obtained, the operation is not allowed to proceed so rapidly as with the more ignoble ores.

A stamp-head of 2 to 3 cwt. stamps in 24 hours 7 to 11 cwt. of ore, or from 2 to 2½ times as much as the older stamp-head of 150 to 200 lbs., which requires nearly the same amount of water in the "cofer," viz., for 10 stamp-heads, 1 cubic foot per minute. Where the heavy heads are used, the water will therefore contain 2 to 3 lbs. of ore in a cubic foot, whilst with the lighter it will hold but 1 lb.; and the concentration will in the former case proceed more rapidly.

The proportion of the various "sorts" of powder produced by the two is:—

	From the heavy stamp-head.	From the light head.
Coarse powder (*rösches mehl*)	11 per cent.	9 per cent.
Middling (*mittleres*)	26 ,,	20 ,,
Fine (*mildes*)	63 ,,	71 ,,

Whence it seems that the lighter heads occasion the greater loss, by stamping "dead," or too fine.

quantity of water employed, must be varied to suit the mode of dissemination and the structure and properties of the ore as well as its matrix. The arrangements, for example, which are applicable to tinstone are ineligible for gold ; and it is doubtful whether such attention has been paid to the subject in this country as to insure the best results.

Our limits would not allow a discussion of some of these points, which the practical ore-dresser knows to be of great importance ; but we may, in passing, advert to the method of pouring the whole of the stamped stuff heterogeneously into one deep pit, as very rude and inferior to the plan adopted in well-conducted mines of the Continent, where a series of troughs of regularly increased widths and diminished angles of inclination sort the "stuff" in different degrees of coarseness, and thus obviate the introduction of some of the after processes. The necessity of *sorting according to volume*, before attempting to *separate the ore* from the deads, must be admitted as an axiom ; and it is evident that, if the water discharged from the stamps be enabled at once to perform this service, instead of manual labour being again required, a considerable gain will be effected in time and expense.

The lower stamps at Goginan contain 24 heads and are employed in pounding up the inferior raggings and very poor orey mixtures : the produce is, as above, washed in a "strake," the rougher part "tyed," and the finer worked in the ordinary buddle.* About 6 feet of the deposit in the body of the "tye" is "tyed" again, and the lower part is thrown away.

The "slime" from the whole of the upper operations is led into a series of "catch-pits," about 8 yards by 5, from which it is taken to a set of "trunking buddles" (*m, Pl.* 12), of excellent construction, in which the revolving vanes and "tormentor" are moved by water power ; and the concentrated stuff is then treated according to circumstances on the common buddles (*k*, *k*).

The finer slimes resulting hence, and from the lower stamps, after deposition in another range of pits, are similarly treated in other "trunking buddles," and finished, as before, by the common buddle and dolly-tub ; and yet, notwithstanding these repeated processes, much of the ore (and that, too, the most argentiferous part) has been reduced to so small a size by the stamps, that it is finally carried away ; and for a mile or two below the mines traces of it may be observed in the brook.

Thus, at length, the ore is brought to the required degree of purity, bearing in point of weight, to the vein-stone first raised from the mine, the ratio of 1 to 24 ; and, after being subjected to a gentle warming in

* At Cwm Sebon mine, the fine slimes from the head of the buddle are dressed on a "frame," which swings on pivots, like the Cornish tin-frame.

the drying-house, is ready for conveyance to the shipping port of Aberystwyth.

The amount of water power applied to these various operations, is as follows :—

	ft.	in.		ft.	in.	
One overshot wheel of	36	0	diameter, and	3	0	breast, draws the ores, and drives a spare crusher.
,, ,, ,,	27	0	,,	2	6	,, works 12 stamp-heads and a crusher.
,, ,, ,,	32	0	,,	2	11	,, ,, 18 stamp-heads and a crusher.
,, ,, ,,	37	0	,,	3	2	,, ,, 24 stamp-heads.
,, ,, ,,	9	0	,,	0	14	,, ,, lower trunking buddle, west.
,, ,, ,,	8	0	,,	0	14	,, ,, trunking buddle near road-side.
,, ,, ,,	8	0	,,	0	12	,, ,, six trunks below slime-pits
,, ,, ,,	6	0	,,	0	3	,, ,, round buddle.
Three ,, ,,	6	8	,,	0	4	,, turn the round griddles.

Although the dressing of ores is generally let by bargain, at a certain rate per ton, it has been found preferable at Goginan to adopt the system of paying day wages; and a strict supervision becomes therefore necessary. It was even proved advisable to discontinue the use of machinery for working the jigging sieves, since the work-people would willingly allow them to be kept in motion a much longer time than was necessary, and their idleness amid the constant rattle was not easily detected.

To conclude our view of the mineral resources of Cardiganshire and Montgomeryshire, the following list presents the whole of the lodes which fell under the notice of the survey in 1846-7, proceeding for convenience from south to north, first in the former and secondly in the the latter county.

Those which are not in work are in italics.

CARDIGANSHIRE.

	NAME OF LODE.	Lead Ore Returns. 1845	Lead Ore Returns. 1846	Number of People Employed.	REMARKS.
		Tons.	Tons.		
1	Llanfair Clydogau .	158	242	?	The most argentiferous lode in the county, 80 ozs. per ton of lead.
2	*Nant fach ddu* . . .	. .	. .	. .	An adit level driven.
3	*Crown mines*, E. of Llanfair	. .	. .	. .	Lately abandoned.

CARDIGANSHIRE—*continued.*

	NAME OF LODE.	Lead Ore Returns. 1845	Lead Ore Returns. 1846	Number of People Employed.	REMARKS.
		Tons.	Tons.		
4	*Rhysgog*, East . . .	..	..	..	One of Sir H. Myddelton's mines; of late unsuccessfully worked.
5	*Rhysgog gadfach.*				
6	*Pentre trinant* . . .	..	..	..	Only a short level driven.
7	*Bron Mwyn* . . .	..	..	..	Worked 40 years ago.
8	*Bryn y Gors* . . .	..	..	..	Trials lately made.
9	Bron y ber-llan . .	..	..	?	Working on a small scale.
10	*Ditto North lode.*				
11	*Cwm Mawr* . . .	..	..	..	An old mine, 35 fathoms deep, and once very productive.
12	*Llwyn Gwyddyl* . .	..	..	..	Extensive old workings.
	Esgair Mwyn . . .	..	..	?	Workings lately resumed.
13	*Esgair ddu.*				
14	*Glog Fawr* . (Lisburne Mines.)				
15	*Glog Fach* . (Lisburne Mines.)				
16	Pen y Gist . (Lisburne Mines.)	2492	1724	500	The Lisburne mines are worked under the management of Mr. John Taylor. The principal lode of Logaulas is again seen on the west at Bwlch y baedd.
17	Pen y Gist, S. Lode . . (Lisburne Mines.)				
18, 19, 20	Logaulas . . (Lisburne Mines.)				
21	Fron goch . . (Lisburne Mines.)		801		
	Graig goch . (Lisburne Mines.)		117		
	Cwm Mwydion (Lisburne Mines.)		5		This lode is part of Grogwynion.
22	Llwyn Malys . . .	60	..	?	This mine is again raising ore.
23	*Ditto, North lode.*				
24	*Pont Rhyd y Groes* .	..	..	..	Large vein of calc spar in the bed of river.
25, 26	Grogwynion, two lodes	..	..	..	Very ancient mine, on which workings are recommenced.
27	*Maen Arthur.*				
28	*Pant ar hyrion* . . .	..	..	..	Very pure ore was here raised from a shallow level.
29	*Tyn y glog.*				
30	*Graig goch* (Cwm Ystwyth) . . .				
31–42	Cwm Ystwyth, 12 main lodes	356	550	150	Extensive though shallow workings on an intricate group of lodes.
43	Pentre Brunant . .	..	..	..	Only a long level driving.
44	*Bodcoll*	..	..	..	A fine lode with promising appearances of galena.
45	*Ty Gwyn and Pen Corbed.*				
46	*Wen allt.*				
47	*Nant syddion.*				
48	*Nant y Creiau, South.*				
49	Nant y Creiau . . .	120	30	50	This mine produces also blende; in 1846, 130 tons.
50	*Blaen Cennant.*				
51	*Allt ddu.*				
52	*Rhiw Rigas* (Rhiw r'agos)	..	..	..	These lodes contain a large proportion of zinc blende.
53	*Ditto, North* . . .				
54	*Daniell's and Nant Glas.*				

Cardiganshire—*continued.*

	NAME OF LODE.	Lead Ore Returns. 1845	Lead Ore Returns. 1846	Number of People Employed.	REMARKS.
		Tons.	Tons.		
55 56 57	Gwaith goch, Estymteon, Pen Rhiw (Nant Eos Mines.)	..	..	36	Worked under the direction of Mr. John Taylor.
	Ditto continued, *Nant Meirch.*				
58	*Aber iffrwyd.*				
59	*Gelli'r Eirin* . . .	..	..	..	Lately abandoned after raising 60 tons of ore.
60	*Ty llwyd*	..	..	..	Twelve tons of ore raised in last working.
61	Bryn glas	10	..	?	
	Ditto at Esgairlly, with cross strings. . .	..	..	..	Working on a small scale.
62	*Ochr rhos.*				
63	*Llewyrnog*	48	..	..	Lately abandoned.
64	*West Llewyrnog.*				
65	Cefn Brwyno . . .	72	32	10	
66	*Llewyrnog cross lode.*				
67	Bog, (*see* Daren infra).	..	50	..	This mine with Daren, worked as the Gogerddan mines.
68	*Nant yr arian.*				
69	*Nant Garedyn* (near Pont Erwyd) . .	..	..	..	Exhibits zinc blende in the bed of a brook.
70 71	Goginan, North lode. Goginan, South lode.	1768	1627	400	Worked under the direction of Mr. John Taylor.
	Bwlch Cwm Erfin. .	30	50	12	
	Cae Nant.				
72 73	Bwlch Cwm Erfin, *South lodes of.*				
74	Level riech and Level newydd	with Goginan.			Worked by the Goginan Company.
75	*Cwm Erfin.*				
76	Cwm Sebon . . .	240	305	70	All the lodes from 70 to 77 inclusive, yield 22 to 32 ounces of silver to the ton of lead.
	Cwm Symlog.				
77	Daren, with No. 67, as the Gogerddan mines produced.	210	76	70	Formerly a very productive mine.
78	*Cwm Canol.*				
79	*Cwm Canol branch.*				
80	*Llechwydd hên*, *Llechwydd helig*, *Llawr y cwm*, *Bwlch y Stytlen*, *Camdwr and Drosgol*	..	..	..	This lode, often of gigantic dimensions, has been traced over a distance of eight miles; it generally bears galena and zinc blende, but at Camdwr iron pyrites, and at Drosgol manganese ores.
81	Llanerch	..	..	?	Small workings lately commenced.
82	*Melyn y bont goch.*				
83	Pen y Cefn. . . .	36	35	15	
84 85 86	*Mynydd Gordu,* three lodes	..	..	..	These lodes are only slightly displayed in trenches.
	Cefn Gwyn	..	..	..	A level driven under Cefn Gwyn house.

CARDIGANSHIRE—*continued.*

	NAME OF LODE.	Lead Ore Returns. 1845	Lead Ore Returns. 1846	Number of People Employed.	REMARKS.
		Tons.	Tons.		
	Moel y Golomen . .	. .	. .	. .	Many small strings of galena.
	Hen fwlch	. .	. .	?	Very powerful lode.
87	*Tal y bont bridge.*				
88 89 , , 92	*Allt y crib, S. lode* *Ditto, North lode* . . *Three South branches* .	25	. .	. .	The Tal y bont mines very successful last century, but lately abandoned from poverty in depth.
93 94 95	Pen y bont Pren, S. lode. Ditto N. lode. . . Ditto cross lode.	. .	. .	. .	Working under the direction of Mr. John Taylor.
96	*Pen y banc*	24	. .	. .	
97	Erglodd.	. .	. .	. .	Ore taken from a small shaft: old workings in the wood above.
98	Tal-i-essin	. .	. .	. .	A north and south lode, said to have been very productive.
99 100 101	Gwarcwm, three lodes.	. .	. .	?	
103	Tre'r ddol	. .	. .	. .	A lode of rich copper pyrites.
104 109	Llancynfelyn, six lodes	. .	4	. .	This mine has lately been re-opened on a large scale, but with little success.
110	Tyn y nant.				
111	Park gate.				
112	Park lodge	. .	. .	?	Worked on a very small scale by men from Tre'r ddol.
113	Trwyn y buarth.				
114	*Melyn y lodge* . . .	. .	. .	. .	Hard lode with only copper pyrites.
115	Esgair hir, with several branches	41	110	30	Very large, and occasionally productive lode.
116	*Rhyd yr henedd.*				
117	*Gabwt.*				
118	*Cwm Einon* . . .	. .	. .	. .	Lately worked on a small scale.
119	*Gwar cwm bach.*				
120	Llwyn Gwyn (1 mile S. of Eglwsfach). .	. .	. .	?	A little galena has lately been found at this place.

MONTGOMERYSHIRE.

1	*Bryn bos ddu,* near Llanidloes . . .	. .	. .	. .	Several hundred tons of ore have been raised from this mine, but it has for some years been abandoned.
2	*Cwm mawr*	. .	. .	. .	A vein chiefly of sulphate of baryta.
3	Gorn	33	43	. .	Galena, zinc blende, and witherite.
4	*Pant mawr*	48 ?	. .	. .	Lode runs nearly N. and S.
5	Siglen las	. .	. .	. .	Galena and copper pyrites have been raised in small quantities.
6	Geufron.	. .	. .	. .	Small but promising lode of galena and copper pyrites.
7	Hafod feddgur . . .	. .	. .	. .	Small quantities of copper ore have been raised here.
, ,	*Gwestyn.*				

MONTGOMERYSHIRE—*continued.*

	NAME OF LODE.	Lead Ore Returns.		Number of People Employed.	REMARKS.
		1845	1846		
		Tons.	Tons.		
7	Bryn y Gaer.				
,,	Bryn dail	130	150	20	Pen y clyn is remarkable for the purity of its masses of galena, and their accompaniment of witherite.
,,	Pen y clyn				
8	*Nant y cawrdre* . . .	..	..	..	Great width of vein stone.
9	Nant Iago	..	20	..	Produces zinc blende in considerable quantity.
10	*Afon Horeg* . . .	..	..	..	Threads of pure galena in sandstone.
11	*Maes-nant.*				
12	Cwm rhicet.				
13	Rhyd dib enwch . .	..	..	4	
14	Nant Melyn . . .	..	..	3	Contains galena and copper pyrites.
15	Dwngwm	25	..	..	Powerful, but very hard lode.
,,	Cefn Delife.				
16	Llechwydd ddu . .	586	557	200	Llechwydd ddu, a rich lode and regularly worked. Esgair Galed averages 15 feet wide, and has been productive in former times.
17	Esgair Galed . . .				
18	Geulan	..	..	4	
19	Bryn bedwen.				
	Cae Conroy . . .	73	34	..	Situated at junction of two lodes, shaft 45 yards deep; ore somewhat argentiferous.
20	Rhos y Gwidol . .	..	52½	20	
,,	Llanerch yr aur.				
21	Rhos y Gwidol, North lode.				
22	*Rhiw Griafol.*				
23	*Penrhiw Mwyn.*				Shallow shafts, long abandoned.
24–26	Cwm byr, three lodes.	..	..	2	Small veins, with threads of galena.
27	*Cwm Rhaiadyr* . .	..	..	..	A long adit level has been driven and abandoned.
28	Llangynnog . . .	115	103	60	This lode was discovered near the end of the 17th century, and was 2 yds. wide of solid ore.
29	Craig Rhiwarth . .	..	30	20	This lode, like the above, is only productive in beds of porphyritic rock which alternate with the slates.
30	Cwm Orog.				
31	*Cwm glan r'afon* . .	..	..	..	28 to 30 contain sulphates and carbonates of baryta.
32	*Cwm wr isaf,* or *Craig ddu.*				
33	Bwlch Creolan. . .	..	..	?	In 33 and 34 baryte is abundant.
34	*Meifod.*				
35	*Rhysnant.*				
36–37	Craig y Mwyn. . .	..	..	2	S. or foot wall of lode more distinct than the other; unproductive in the slate, but yielding galena, blende, and witherite, in the beds of porphyritic rock.
38	*Moel Uchlas* . .	..	..	..	A small lode, with galena, in irregular arenaceous slates.

On the Composition of some of the Limestones used for Building purposes, especially on those employed in the erection of the New Houses of Parliament. By Thomas Ransome and Benjamin Cooper, Assistants in the Laboratory of the Museum.

The decomposition of the materials of which most public works and national monuments are composed, is a subject of great importance, yet it does not appear that much attention has been directed to discover the causes by which it is influenced. Owing either to neglect, or ignorance in the choice of a proper material, many of our most beautiful cathedrals and churches are in a more or less dilapidated condition: in some cases the carvings and enrichments have entirely or partially disappeared; while in others, where a good stone has been selected, they are as perfect as when first cut, the chisel-marks being still apparent. In the year 1839 a Commission was appointed by Her Majesty's Government to select the best stone for the erection of the new Houses of Parliament. Their report contains a large amount of valuable information, and includes the analyses of sixteen varieties of stone by the late Professor Daniell; but in these analyses it was thought unnecessary to estimate the small quantities of soda, chlorine, and sulphuric acid, which some of them contain, or to separate the per- and protoxide of iron. We have at present, with one exception, only extended our inquiry to a few of the oolitic and magnesian limestones; of these, the first four were selected because the buildings in which they have been used are in very different states of preservation, and we hoped that by careful chemical analysis, and by the determination of the quantity of the minute ingredients, something might be done towards explaining the causes of their unequal durability. The remaining eight have been used in the new Houses of Parliament, which circumstance, together with their being generally very durable stones, rendered them an interesting series for analysis. The analyses were made in the laboratory of the Museum of Practical Geology, at the request of Dr. Lyon Playfair.

We will first describe the manner in which the quantitative analyses were performed. A known weight of the stone was heated to dull redness, and the loss considered as water, except in the case of the magnesian limestones, which were found to lose some of their carbonic acid; with them a separate portion was taken and heated in a glass tube connected with another filled with fragments of chloride of calcium, which latter was weighed both before and after the experiment, the

increase being the amount of water. The stone was then dissolved in hydrochloric acid, and, if manganese was not present, it was boiled with a small quantity of nitric acid to peroxidize the iron, and then precipitated by ammonia; the precipitated peroxide of iron and alumina (if present) were then separated by caustic soda in the usual manner. The lime was precipitated from the filtrate by oxalate of ammonia, ignited and weighed as carbonate. If the stone did not contain soda, the magnesia was precipitated from the concentrated solution by phosphate of soda, and, after ignition, was weighed as the bi-basic phosphate of magnesia. If, however, alkalies were present, the filtrate from the oxalate of lime was evaporated to dryness, and heated to expel ammoniacal salts, the residue re-dissolved in a small quantity of water, and the magnesia precipitated by solution of caustic barytes, and afterwards dissolved in sulphuric acid, and precipitated by phosphate of soda and ammonia. The barytes in solution with the alkalies was then separated by boiling with carbonate of ammonia and filtering. The filtrate, neutralized with hydrochloric acid, evaporated to dryness and gently ignited, gave the quantity of soda as chloride of sodium. When manganese was present, the solution in hydrochloric acid, after filtration from the insoluble matter, was neutralized with ammonia, and the iron and manganese precipitated by hydrosulphuret of ammonia, the filtrate boiled with hydrochloric acid to decompose the hydrosulphuret, and filtered to separate sulphur. The lime, magnesia, and soda were estimated as before. The precipitate was re-dissolved in hydrochloric acid, and the iron peroxydized by nitric acid, the solution nearly neutralized by ammonia, and carbonate of barytes added, until the whole of the peroxide of iron was precipitated. The solution was then filtered, and the iron separated from the undissolved carbonate of barytes by sulphuric acid, and afterwards precipitated by ammonia.

The barytes, in the solution containing the manganese, was precipitated by sulphuric acid, the filtrate nearly neutralized by caustic soda, and the manganese precipitated as carbonate by boiling with carbonate of potash until the ammoniacal salts were completely decomposed; it was then ignited and weighed as the red oxide. When the stone contained both oxides of iron a separate portion was taken, from the solution of which in hydrochloric acid the peroxide was precipitated by carbonate of barytes, in the same manner as when separated from manganese. The protoxide of iron in solution was then converted into peroxide by nitric acid, and precipitated by ammonia; from the amount of peroxide obtained the quantity of protoxide was calculated. The chlorine was estimated as chloride of silver, and obtained by precipitating a solution of the stone in nitric acid by nitrate of silver. The sulphuric acid was calculated from the weight of sulphate of barytes

obtained by adding chlorine of barium to a solution of the stone in hydrochloric acid. The phosphoric acid was not in sufficiently large quantity to be estimated.

The carbonic acid was taken as loss upon decomposing a known weight of stone by hydrochloric acid in a flask, with a small tube, containing chloride of calcium attached, so as to dry the gas during its escape. The specific gravity was taken by introducing a weighed quantity of the stone in coarse powder into a volumenometer,* graduated to grain measures, and filled up to 0° with boiled water. The weight of stone employed, divided by the increase, gives the specific gravity.

Oolitic Limestone from Downside, Brockley Combe, near Bristol.

This limestone is easily decomposed by hydrochloric acid, but does not entirely dissolve; the insoluble part consists principally of silica, with very slight traces of alumina and lime. The soluble portion contains peroxide of iron, protoxides of iron, and manganese, lime and magnesia.

The specific gravity was taken by the volumenometer. 40 grains gave an increase of 14·9; 100 grains increased 37·3. This gives the specific gravity by the first experiment 2·684; by the second, 2·680. Mean 2·682.

First Analysis.

29·02 grs. gave ·14 grs. of water = 48 per cent.
1·40 grs. of insoluble matter.
·12 grs. of peroxide of iron = ·28 per cent.
26·75 grs. of carbonate of lime = 92·17 per cent. = 51·86 of lime.
·13 grs. of phosphate of magnesia = ·16 per cent. of magnesia.
·15 grs. of red oxide of manganese = ·48 per cent. of protoxide.
24·34 grs. yielded ·05 grs. of peroxide of iron = 20 per cent. of peroxide, and ·05 grs. of peroxide by the oxydation of the protoxide = ·18 per cent. of protoxide of iron.
20·49 grs. lost 8·39 grs. of carbonic acid = 40·95 per cent.

Second Analysis.

29·54 grs. gave ·14 grs. of water = ·47 per cent.
1·7 grs. of insoluble matter = 4·64 per cent.
·13 grs. of peroxide of iron = ·44 per cent.
·11 grs. red oxide of manganese = 34 per cent. of protoxide.

* This instrument is fully described in a paper on "Atomic Volumes," by Messrs. Playfair and Joule (Chemical Society's Memoirs, vol. ii. p. 401).

27·35 grs. of carbonate of lime = 92·58 per cent = 52·11 of lime.
·10 grs. of phosphate of magnesia = ·12 per cent. of magnesia.
26·20 grs. gave ·07 grs. of peroxide of iron = ·27 per cent.
·06 grs. of peroxide from the protoxide = ·21 per cent.
27·24 grs. lost 11·16 grs. of carbonic acid = 40·46 per cent.

	I.	II.
Water	·48	·47
Silica	4·82	4·64
Protoxide of Manganese	·48	·34
——— Iron	·18	·21
Peroxide of Iron	·28	·27
Lime	51·86	52·11
Magnesia	·16	·12
Carbonic Acid	40·95	40·96
	99·21	99·12

	I.	II.
Water	·48	·47
Silica	4·82	4·64
Peroxide of Iron	·20	·27
Carbonate of Manganese	·77	·55
——— Iron	·29	·34
——— Lime	92·17	92·58
——— Magnesia	·34	·25
	99·07	99·10

Oolitic Limestone, Dundry, near Bristol.

The church of St. Mary Redcliffe is built of this stone, and is much decomposed. The tower is of the twelfth, the body of the church of the fifteenth century. It is easily decomposed by hydrochloric acid, only a very small quantity remaining undissolved. The solution contains protoxide of iron, alumina, lime, magnesia, soda, and sulphuric acid. The latter is probably combined in part with lime, for, upon digesting the powdered stone for a short time in cold water, the filtered solution contains both lime and sulphuric acid; if, however, it is boiled for a long time, the solution then contains a much smaller proportion of lime, but it also contains soda. This may arise from the sulphate of lime acting upon the carbonate of soda, which probably exists as the insoluble carbonate of soda and lime, for no carbonic acid could be detected in the residue, after evaporating the aqueous solution to dryness.

40 grains gave an increase in the volumenometer of 14·6 in the first, and 14·7 in the second experiment, which makes the specific gravity 2·739 and 2·721 respectively. Mean 2·730.

First Analysis.

25·63 grs. gave ·19 grs. of water = ·74 per cent.
·24 grs. of silica = ·93 per cent.
·21 grs. of peroxide of iron = ·72 per cent. of protoxide.
·08 grs. of alumina = ·31 per cent.
24·53 grs. of carbonate of lime = 53·65 per cent. of lime.
·22 grs. of phosphate of magnesia = ·32 per cent. of magnesia.
·18 grs. of chloride of sodium = ·38 per cent. of soda.
23·92 grs. lost 10·11 grs. of carbonic acid = 42·26 per cent.
·08 grs. of sulphate of barytes = ·11 per cent. of sulphuric acid.

Second Analysis.

27·33 grs. gave ·25 grs. of water = ·91 per cent.
·16 grs. of silica = ·58 per cent.
·26 grs. of peroxide of iron = ·85 per cent. of protoxide.
·08 grs. of alumina = ·29 per cent.
25·98 grs. of carbonate of lime = 53·51 per cent. of lime.
·23 grs. of phosphate of magnesia = ·31 per cent. of magnesia.
·18 grs. of chloride of sodium = ·35 per cent. of soda.
23·69 grs. lost 9·55 grs. of carbonic acid = 42·00 per cent.
67·85 grs. gave ·26 grs. of sulphate of barytes = ·13 per cent. of sulphuric acid.

	I.	II.
Water	·74	·91
Silica	·93	·58
Protoxide of Iron	·72	·85
Alumina	·31	·29
Lime	53·65	53·51
Magnesia	·32	·31
Soda	·38	·35
Sulphuric Acid	·11	·13
Carbonic Acid	42·26	42·00
	99·42	98·93

	I.	II.
Water	·74	·91
Silica	·93	·58
Protoxide of Iron	·72	·85
Alumina	·31	·29
Carbonate of Lime	95·22	94·96
——— Magnesia	·66	·64
——— Soda	·64	·59
Sulphate of Lime	·16	·19
	99·38	99·01

Oolitic Limestone, Combe Down, Bath.

This stone was used in the restoration of Henry the Seventh's chapel, Westminster Abbey, and though only about twenty-five years since, is already in a state of decay. Hydrochloric acid easily decomposes it, leaving a very small quantity undissolved. It consists of lime, protoxide of iron, alumina, magnesia, and soda, with carbonic acid, a trace of sulphuric acid and chlorine, the latter united with part of the sodium, forming common salt, which is dissolved out by boiling the powdered stone in water.

40 grains introduced into the volumenometer gave an increase, in the first experiment, of 14·8, equal to a specific gravity of 2·702; in the second, of 15·0, which makes the specific gravity 2·666. Mean 2·684.

First Analysis.

26·14 grs. gave ·23 grs. of water = ·88 per cent.
·11 grs. of silica = ·42 per cent.
·36 grs. of peroxide of iron = 1·22 per cent. of protoxide.
·12 grs. of alumina = ·46 per cent.
24·87 grs. of carbonate of lime = 53·55 per cent. of lime.
·23 grs. of phosphate of magnesia = ·32 per cent. of magnesia.
23·51 grs., after separating the lime, magnesia, iron, and alumina, gave ·19 grs. of chloride of sodium = ·44 per cent. of soda.
20·36 grs. lost 8·56 grs. of carbonic acid = 42·04 per cent.
26·77 grs. gave ·04 grs. of chloride of silver = ·03 per cent. of chlorine.

Second Analysis.

25·84 grs. gave ·19 grs. of water = ·74 per cent.
·22 grs. of silica = ·85 per cent.
·34 grs. of peroxide of iron = 1·04 per cent. of protoxide.
·16 grs. of alumina = ·61 per cent.
24·74 grs. of carbonate of lime = 53·89 per cent. of lime.
·16 grs. of phosphate of magnesia = ·23 per cent. of magnesia.
·21 grs. of chloride of sodium = ·44 per cent. of soda.
27·00 grs. lost 11·38 grs. of carbonic acid = 42·14 per cent.
47·23 grs. gave ·07 grs. of chloride of silver = ·03 per cent. of chlorine.

	I.	II.
Water	·88	·74
Silica	·42	·85
Protoxide of Iron	1·22	1·04
Alumina	·46	·61
Lime	53·55	53·89
Magnesia	·32	·23
Soda	·44	·44
Sulphuric Acid	a trace.	a trace.
Chlorine	·03	·03
Carbonic Acid	42·04	42·14
	99·36	99·97

	I.	II.
Water	·88	·74
Silica	·42	·85
Protoxide of Iron	1·22	1·04
Alumina	·46	·61
Carbonate of Lime	95·14	95·74
——— Soda	·71	·71
Magnesia	·32	·23
Chloride of Sodium	·05	·05
	99·20	99·97

Oolitic Limestone, Grove Quarry, Red Croft, Island of Portland, Dorsetshire.

St. Paul's Cathedral is built of this stone, and is generally in good condition. It is readily decomposed by hydrochloric acid; the undissolved part consists of silica in fine white grains. The soluble part contains lime, magnesia, soda, iron, and alumina. The quantity of iron is very small, and is entirely in the state of protoxide; the quantity of alumina is also very small, and in the second analysis it is estimated along with the iron. It also contains a trace of phosphoric acid.

40 grains gave an increase in the volumenometer of 15·2 in two experiments, equal to a specific gravity of 2·631.

First Analysis.

26·49 grs. gave ·16 grs. of water = ·60 per cent.
·25 grs. of silica = ·94 per cent.
·08 grs. of peroxide of iron = ·30 per cent.
·02 grs. of alumina = ·07 per cent.
25·48 grs. of carbonate of lime = 54·14 per cent. of lime.
·37 grs. of phosphate of magnesia = ·51 per cent. of magnesia.
·16 grs. of chloride of sodium = ·33 per cent. of soda.
26·68 grs. lost 12·29 grs. of carbonic acid = 42·91 per cent.

Second Analysis.

23·85 grs. gave ·16 grs. of water = ·67 per cent.
·18 grs. of silica = ·75 per cent.
·08 grs. of peroxide of iron and alumina = ·33 per cent.
23·06 grs. of carbonate of lime = 54·42 per cent. of lime.
·34 grs. of phosphate of magnesia = ·51 per cent. of magnesia.
·15 grs. of chloride of sodium = ·36 per cent. of soda.
20·30 grs. lost 8·74 grs. of carbonic acid = 43·05 per cent.

	I.	II.
Water	·60	·67
Silica	·94	·75
Peroxide of Iron . . .	·30	·33
Alumina	·07	
Lime	54·14	54·42
Magnesia	·51	·51
Soda	·33	·34
Carbonic Acid	42·91	43·05
Phosphoric Acid . . .	a trace.	a trace.
	99·80	100·07

	I.	II.
Water	·60	·67
Silica	·94	·75
Peroxide of Iron . . .	·30	·33
Alumina	·07	
Carbonate of Lime . . .	96·18	96·68
——— Magnesia .	1·05	1·05
——— Soda	·56	·58
Phosphoric Acid . . .	a trace.	a trace.
	99·70	100·06

Oolitic Limestone, Caen, Normandy.

This stone is very fine grained, and easily cut with a knife; it is used in part of Westminster Abbey, in Canterbury Cathedral, and also for internal work in the new Houses of Parliament. It is easily decomposed by hydrochloric acid, a considerable portion of almost pure silica remaining undissolved; the soluble part consists of protoxide of iron, lime, and magnesia.

40 grains introduced into the volumenometer gave an increase of 15·0 in the first, and 15·4 in the second experiment, which make the specific gravity 2·666 and 2·597. Mean 2·631.

First Analysis.

24·06 grs. gave ·46 grs. of water = 1·91 per cent.
3·30 grs. of silica = 13·71 per cent.
·20 grs. of peroxide of iron = ·73 per cent. of protoxide.
19·87 grs. of carbonate of lime = 46·48 per cent. of lime.
·32 grs. of phosphate of magnesia = ·48 per cent. of magnesia.
22·01 grs. lost 8·06 grs. of carbonic acid = 36·11 per cent.

Second Analysis.

24·91 grs. gave ·32 grs. of water = 1·28 per cent.
3·37 grs. of silica = 13·53 per cent.
·20 grs. of peroxide of iron = ·72 per cent. of protoxide.

20·52 grs. of carbonate of lime = 46·37 per cent of lime.
·36 grs. of phosphate of magnesia = ·52 per cent. of magnesia
25·38 grs. lost 9·15 grs. of carbonic acid = 36·05 per cent.

	I.	II.
Water	1·91	1·28
Silica	13·71	13·53
Protoxide of Iron	·73	·72
Lime	46·48	46·37
Magnesia	·48	52
Carbonic Acid	36·11	36·05
	99·42	98·47

	I.	II.
Water	1·91	1·28
Silica	13·71	13·53
Protoxide of Iron	·73	·72
Carbonate of Lime	82·58	82·38
Magnesia	·48	·52
	99·41	98·43

The magnesia and iron are most probably in the state of silicates.

Oolitic Limestone, Painswick, Gloucestershire.

Used for internal work in the new Houses of Parliament. It is very easily decomposed by hydrochloric acid, and contains silica, protoxide of iron, lime, magnesia, soda, and carbonic acid, with a slight trace of chlorine.

40 grains gave an increase in the volumenometer, in the first experiment, of 15·5; in the second, 15·2. Specific gravity by the first experiment 2·580, by the second 2·631. Mean 2·605.

First Analysis.

28·04 grs. gave ·16 grs. of water = ·57 per cent.
·07 grs. of silica = ·25 per cent.
·14 grs. of peroxide of iron = ·40 per cent of protoxide.
27·38 grs. of carbonate of lime = 54·96 per cent. of lime.
·29 grs. of phosphate of magnesia = ·38 per cent. of magnesia.
·20 grs. of chloride of sodium = ·39 per cent. of soda.
25·39 grs. lost 11·02 grs. of carbonic acid = 43·40 per cent.

Second Analysis.

20·34 grs. gave ·19 grs. of water = ·93 per cent
·09 grs. of peroxide of iron = ·39 per cent. of protoxide.
19·85 grs. of carbonate of lime = 54·93 per cent. of lime.
·23 grs. of phosphate of magnesia = ·41 per cent. of magnesia.
·17 grs. of chloride of sodium = ·45 per cent. of soda.
13·13 grs. lost 5·27 grs. of carbonic acid = 43·44 per cent.

	I.	II.
Water	·57	·93
Silica	·25	·19
Protoxide of Iron . . .	·40	·39
Lime	54·96	54·93
Magnesia	·38	·41
Soda	·39	·45
Chlorine	a trace.	a trace.
Carbonic Acid	43·40	43·44
	100·35	100·74

	I.	II.
Water	·57	·93
Silica	·25	·19
Protoxide of Iron . . .	·40	·39
Carbonate of Lime . . .	97·64	97·59
——— Magnesia .	·78	·85
——— Soda . . .	·66	·76
Chlorine	a trace.	a trace.
	100·30	100·71

Magnesian Limestone, Bolsover Moor, Derbyshire.

Southwell Church is built of this stone, and is in very perfect condition. It is of a yellowish-brown colour, and semi-crystalline structure; is decomposable by hydrochloric acid, though not readily, unless heat be applied, and consists of silica, per- and protoxide of iron, a trace of manganese, lime, magnesia, and carbonic acid.

40 grains gave an increase in the volumenometer, in the first experiment, of 14·3; in the second, of 14·2; which makes the specific gravity 2·797 and 2·816. Mean 2·806.

First Analysis.

38·87 grs. gave ·17 grs. of water = ·46 per cent.
28·83 grs. gave 1·05 grs. of silica = 3·64 per cent.
·52 grs. of peroxide of iron = 1·80 per cent.
15·08 grs. of carbonate of lime = 29·24 per cent. of lime.
15·35 grs. of phosphate of magnesia = 19·49 grs. per cent. of magnesia.
29·79 grs. lost 13·09 grs. of carbonic acid = 43·94 per cent., and gave
·28 grs. of peroxide of iron, from the oxydation of the protoxide = ·84 per cent. of protoxide.
·25 grs. of peroxide = ·84 per cent.

Second Analysis.

24·43 grs. gave ·12 grs. of water = ·49 per cent.
29·60 grs. gave 1·08 grs. of silica = 3·64 per cent.
·55 grs. of peroxide of iron = 1·85 per cent.

15·45 grs. of carbonate of lime = 29·37 per cent. of lime.
15·94 grs. of phosphate of magnesia = 19·74 per cent.
21·09 grs. lost 9·27 grs. of carbonic acid = 44·03 per cent., and gave
·26 grs. of peroxide of iron, from the protoxide = ·93 per cent. of protoxide.
·20 grs. of peroxide = ·81 per cent.

	I.	II.
Water	·46	·49
Silica	3·64	3·64
Protoxide of Iron . . .	·84	·93
Peroxide of Iron . . .	·84	·81
Oxide of Manganese . .	a trace.	a trace.
Lime	29·24	29·37
Magnesia	19·49	19·74
Carbonic Acid	43·94	44·03
	98·45	99·01

	I.	II.
Water	·46	·49
Silica	3·64	3·64
Protoxide of Iron . . .	·84	·93
Peroxide of Iron . . .	·84	·81
Oxide of Manganese . .	a trace.	a trace.
Carbonate of Lime . .	51·95	52·19
——— Magnesia .	40·36	40·84
	98·09	98·90

Magnesian Limestone, North Anston, between Worksop and Sheffield, Yorkshire.

This stone is of the same colour as the last, only rather darker; it is also semi-crystalline, and not very easily decomposed by cold hydrochloric acid. It consists of silica, per- and protoxide of iron, a trace of manganese, lime, magnesia, and carbonic acid.

40 grains gave an increase in the volumenometer of 14·2 in two experiments. Specific gravity 2·816.

First Analysis.

41·99 grs. gave ·22 grs. of water = ·52 per cent.
26·33 grs. gave ·15 grs. of silica = ·57 per cent.
·22 grs. of peroxide of iron = ·83 per cent.
14·43 grs. of carbonate of lime = 30·84 per cent. of lime.
14·58 grs. of phosphate of magnesia = 20·30 per cent.
32·74 grs. lost 14·97 grs. of carbonic acid = 45·72 per cent.
29·83 grs. gave ·07 grs. of peroxide of iron = ·24 per cent.
·15 grs. of peroxide of iron from the protoxide = ·45 per cent. of protoxide.

Second Analysis.

28·49 grs. gave ·14 grs. of water = ·49 per cent.
26·64 grs. gave ·15 grs. of silica = ·56 per cent.
·25 grs. of peroxide of iron = ·93 per cent.
14·65 grs. of carbonate of lime = 30·95 per cent. of lime.
14·68 grs. of phosphate of magnesia = 20·37 per cent. of magnesia.
27·94 grs. lost 12·81 grs. of carbonic acid = 45·84 per cent., and gave
·07 grs. of peroxide of iron = ·25 per cent.
·16 grs. of peroxide of iron from the protoxide = ·52 per cent. of protoxide.

	I.	II
Water	·52	·49
Silica	·57	·56
Protoxide of Iron . . .	·45	·52
Peroxide of Iron . . .	·24	·25
Protoxide of Manganese .	a trace.	a trace.
Lime	30·84	30·95
Magnesia	20·30	20·37
Carbonic Acid	45·72	45·84
	98·64	98·98

	I.	II.
Water	·52	·49
Silica	·57	·56
Protoxide of Iron . . .	·45	·52
Peroxide of Iron . . .	·24	·25
Oxide of Manganese . .	a trace.	a trace.
Carbonate of Lime . . .	54·80	54·99
——— Magnesia .	42·00	42·14
	98·58	98·95

Magnesian Limestone, Stone Ends, North Anston, between Worksop and Sheffield, Yorkshire.

It is used in the new Houses of Parliament, for the plinth towards the river. This stone resembles the last in texture, but is of a rather lighter colour; it differs from it also in its chemical composition, containing much more manganese, and no peroxide of iron.

40 grains gave an increase in the volumenometer, in the first experiment, of 14·3; in the second, of 14·2, which makes the specific gravity 2·797 and 2·816. Mean 2·806.

First Analysis.

22·48 grs. gave ·10 grs. of water = ·44 per cent.
24·48 grs. gave ·21 grs. of silica = ·86 per cent.
·20 grs. of peroxide of iron = ·73 per cent. of protoxide.
·44 grs. of red oxide of manganese = 1·66 per cent. of protoxide.

13·54 grs. of carbonate of lime = 31·13 per cent. of lime.
13·32 grs. of phosphate of magnesia = 20·05 per cent. of magnesia.
18·99 grs. lost 8·69 grs. of carbonic acid = 45·76 per cent.

Second Analysis.

26·06 grs. gave ·12 grs. of water = ·46 per cent.
22·32 grs. gave ·22 grs. of silica = ·98 per cent.
·18 grs. of peroxide of iron = ·72 per cent. of protoxide.
·41 grs. of red oxide of manganese = 1·70 per cent. of protoxide.
12·37 grs. of carbonate of lime = 31·19 per cent. of lime.
12·34 grs. of phosphate of magnesia = 20·27 per cent. of magnesia.
22·23 grs. lost 10·25 grs. of carbonic acid = 45·92 per cent.

	I.	II.
Water	·44	·46
Silica	·86	·98
Protoxide of Iron	·73	·72
——— Manganese	1·66	1·70
Lime	31·13	31·19
Magnesia	20·05	20·27
Carbonic Acid	45·76	45·92
	100·63	101·24

	I.	II.
Water	·44	·46
Silica	·86	·98
Protoxide of Iron	·73	·72
——— Manganese	1·66	1·70
Carbonate of Lime	55·31	55·42
——— Magnesia	41·48	41·94
	100·48	101·22

Magnesian Limestone, Woodhouse, Nottinghamshire.

This stone is of a light-brown colour, and contains small black specks. It is gradually decomposed by hydrochloric acid, and consists of silica, protoxide of iron, protoxide of manganese, lime, magnesia, and carbonic acid.

40 grains gave an increase in the volumenometer of 14·3 in two experiments, which makes the specific gravity 2·797.

First Analysis.

26·35 grs. gave ·06 grs. of water = ·23 per cent.
25·40 grs. gave ·12 grs. of silica = ·47 per cent.
·19 grs. of peroxide of iron = ·66 per cent. of protoxide.
·29 grs. of red oxide of manganese = 1·06 per cent. of protoxide.

13·40 grs. of carbonate of lime = 29·78 per cent. of lime.
14·78 grs. of phosphate of magnesia = 21·33 per cent. of magnesia.
23·46 grs. lost 10·93 grs. of carbonic acid = 46·59 per cent.

Second Analysis.

30·10 grs. gave ·07 grs. of water = ·23 per cent.
25·12 grs. gave ·12 grs. of silica = ·48 per cent.
·17 grs. of peroxide of iron = ·60 per cent. of protoxide.
·33 grs. of red oxide of manganese = 1·22 per cent. of protoxide.
13·27 grs. of carbonate of lime = 29·73 per cent. of lime.
14·74 grs. of phosphate of magnesia = 21·51 per cent. of magnesia.
23·80 grs. lost 11·09 grs. of carbonic acid = 44·59 per cent.

	I.	II.
Water	·23	·23
Silica	·47	·48
Protoxide of Iron	·66	·60
——— Manganese	1·06	1·22
Lime	29·70	29·73
Magnesia	21·33	21·51
Carbonic Acid	46·59	46·59
	100·04	100·36

	I.	II.
Water	·23	·23
Silica	·47	·48
Protoxide of Iron	·66	·60
Carbonate of Manganese	1·71	1·97
——— Lime	52·77	52·82
——— Magnesia	44·13	44·50
	99·97	100·60

Magnesian Limestone, Lindley's Bolsover Quarry, Woodhouse, near Mansfield, Nottinghamshire.

This stone is of a brownish colour, and is slowly decomposed by hydrochloric acid. It consists of silica, per- and protoxide of iron, oxide of manganese, lime, magnesia, and carbonic acid.

40 grains gave an increase in the volumenometer of 14·2 in two experiments; the specific gravity is therefore 2·816.

First Analysis.

25·83 grs. gave ·11 grs. of water = ·43 per cent.
30·21 grs. gave ·33 grs. of silica = 1·08 per cent.
·47 grs. of peroxide of iron = 1·55 per cent.
·49 grs. of red oxide of manganese = 1·50 per cent. of protoxide.

16·38 grs. of carbonate of lime = 30·52 per cent. of lime.
15·36 grs. of phosphate of magnesia = 18·64 per cent. of magnesia.
20·10 grs. lost 9·00 grs. of carbonic acid = 44·77 per cent.
29·03 grs. gave ·26 grs. of peroxide of iron, from the protoxide = ·74 per cent. of protoxide.
·21 grs. of peroxide = ·72 per cent.

Second Analysis.

26·68 grs. gave ·13 grs. of water = ·48 per cent.
23·85 grs. gave ·36 grs. of silica = 1·51 per cent.
·32 grs. of peroxide of iron = 1·34 per cent.
·39 grs. of red oxide of manganese = 1·51 per cent. of protoxide.
12·85 grs. of carbonate of lime = 53·87 per cent. of lime.
12·53 grs. of phosphate of magnesia = 18·66 per cent. of magnesia.
20·53 grs. lost 9·14 grs. of carbonic acid = 44·51 per cent.
26·79 grs. gave ·22 grs. of peroxide of iron from the protoxide = ·74 per cent. of protoxide.
·14 grs. of peroxide = ·52 per cent.

	I.	II.
Water	·43	·48
Silica	1·08	1·51
Protoxide of Iron . . .	·74	·74
Peroxide of Iron . . .	·72	·52
Protoxide of Manganese .	1·50	1·51
Lime	30·52	30·32
Magnesia	18·64	18·66
Carbonic Acid	44·77	44·51
	98·40	98·25

	I.	II.
Water	·43	·48
Silica	1·08	1·51
Protoxide of Iron . . .	·74	·74
Peroxide of Iron . . .	·72	·52
Carbonate of Manganese .	2·43	2·44
——— Lime . .	54·22	53·87
——— Magnesia .	38·56	38·60
	98·18	98·16

Magnesian Limestone, Steetly, between Worksop and Chesterfield, Derbyshire.

Used for small internal work in the new Houses of Parliament. This stone is more easily decomposed by hydrochloric acid than the other magnesian limestones which we have examined. It contains

silica, protoxide of iron, lime, magnesia, carbonic acid, and a trace of sulphuric acid.

40 grains gave an increase in the volumenometer of 13·7 in two experiments, which makes the specific gravity 2·919.

First Analysis.

32·24 grs. gave ·04 grs. of water = ·12 per cent.
28·81 grs. gave ·12 grs. of silica = ·42 per cent.
·21 grs. of peroxide of iron = ·64 per cent. of protoxide.
15·51 grs. of carbonate of lime = 30·31 per cent. of lime.
16·90 grs. of phosphate of magnesia = 21·51 per cent. of magnesia.
15·54 grs. lost 7·22 grs. of carbonic acid = 46·46 per cent.

Second Analysis.

29·93 grs. gave ·04 grs. of water = ·13 per cent.
26·11 grs. gave ·12 grs. of silica = ·45 per cent.
·19 grs. of peroxide of iron = ·64 per cent. of protoxide.
14·11 grs. of carbonate of lime = 30·42 per cent. of lime.
14·83 grs. of phosphate of magnesia = 20·81 per cent. of magnesia.
21·29 grs. lost 9·89 grs. of carbonic acid = 46·45 per cent.

	I.	II.
Water	·12	·13
Silica	·42	·45
Protoxide of Iron	·64	·64
Lime	30·31	30·42
Magnesia	21·51	20·82
Carbonic Acid	46·46	46·45
Sulphuric Acid	a trace.	a trace.
	99·46	98·91

	I.	II.
Water	·12	·13
Silica	·42	·45
Protoxide of Iron	·64	·64
Carbonate of Lime	53·85	54·04
——— Magnesia	44·50	43·07
Sulphate of Lime	a trace.	a trace.
	99·53	98·33

For convenience of reference we have, in the following Table, given the mean results of the foregoing analyses.

Table of Mean Results.

—	Downside, Brockley Combe, near Bristol.	Dundry, near Bristol.	Combe Down, Bath.	Grove Quarry, Portland.	Caen, Normandy.	Painswick, Gloucestershire.	Bolsover Moor, Derbyshire.	North Anston, Yorkshire.	Stone Ends, North Anston, Yorkshire.	Woodhouse, Nottinghamshire.	Bolsover Quarry, Woodhouse, Nottinghamshire.	Steetly, Derbyshire.
Water	·48	·82	·81	·63	1·59	·75	·47	·50	·45	·23	·45	·13
Silica	4·73	·76	·63	·85	13·62	·22	3·64	·57	·92	·47	1·30	·43
Protoxide of Manganese	·41	..	..	..	..	..	a trace.	a trace.	1·68	1·14	1·50	..
Protoxide of Iron	·19	·79	1·13	..	·73	·40	·89	·25	·73	·63	·74	·64
Peroxide of Iron	·24	..	..	·30	..	..	·82	·48	..	..	·62	..
Alumina	..	·30	·54	·07	..	..	..	..	..	..	..	..
Lime	51·98	53·58	53·72	54·28	46·42	54·94	29·30	31·89	31·16	29·71	30·42	30·37
Magnesia	·14	·32	·28	·51	·50	·39	19·62	20·34	20·16	21·42	18·65	21·16
Soda	..	·36	·44	·33	..	·42	..	..	..	..	..	..
Carbonic Acid	40·94	42·13	42·07	42·98	36·08	43·42	43·98	45·78	45·84	46·59	44·64	46·46
Sulphuric Acid	..	·12	a trace.	..	..	..	..	..	..	..	..	a trace.
Phosphoric Acid	..	..	..	a trace.	..	..	..	..	..	..	..	..
Chlorine	..	..	·03	..	..	a trace.	..	..	..	..	..	..
Total	99·12	99·18	99·65	99·95	98·94	100·54	98·72	98·81	100·94	100·19	98·32	99·19
Specific Gravity	2·682	2·730	2·684	2·631	2·631	2·605	2·806	2·816	2·806	2·797	2·816	2·919

From the small number of stones analysed, it would be premature to draw any very general conclusions. So far as we have examined, those stones which are the least durable contain a soluble salt of either lime or sodium; this is the case with the Dundry, Combe Down, and Painswick oolites; the first of which contains sulphate of lime, the two last chloride of sodium; in the Painswick, however, only a very slight trace is present. This stone is very soft, and easily cut with a knife; and, though not very durable, is more so than the preceding. The church of St. Mary's Redcliffe is built of the first, and the second was used in the restoration of Henry the Seventh's chapel, Westminster Abbey, both of which are considerably decayed. It will be observed in the foregoing analyses that several of them contain carbonate of soda, but this does not exist in the stone in a soluble state, but probably as the double carbonate of soda and lime; for, if some of the powdered stone be heated to redness for a short time, the residue left, on evaporating the solution to dryness, contains soda, and effervesces upon the addition of an acid. The quantity of soluble salts in these stones is certainly small, but the process of disintegration is usually extended over a considerable period of time, and small causes when long continued produce very appreciable effects. We do not, however, mean to say that the presence or absence of soluble salts will account for the difference in durability between any varieties of stone, but merely to state, that so far as we have examined, they are either altogether absent, or are present in only small quantities in durable kinds.

Much, doubtless, depends upon the physical condition of the stone, and it is stated in the valuable report before alluded to, that, other things being equal, those stones which are the most crystalline are also the most durable. In conclusion we would remark, that the protoxide of iron has been said to exert considerable influence in hastening disintegration, by absorbing oxygen from the atmosphere and becoming peroxide, yellow or reddish-brown stains of which are frequently observed in decayed stone. But in the specimens of stone we have analysed, there does not appear to be any larger quantity of this oxide in those which are the most decayed. The Combe Down stone contains one-fourth more of the protoxide of iron than the very durable Bolsover Moor stone, while the Dundry contains less. There is, however, this difference, that the Bolsover stone is crystalline, and the other two are not.

But this objection will not apply to the Caen stone, which contains no soluble salts, but as much protoxide of iron as the less durable Dundry stone. From these few instances it would appear, that the protoxide of iron does not exercise any very decided influence in hastening disintegration, but that its conversion into the peroxide is one of the effects and not one of the causes of decay.

Produce of Lead Ore and Lead in the United Kingdom for the Years 1845 *and* 1846; from Returns made to the Mining Record Office, Museum of Practical Geology. Robert Hunt, Keeper of Mining Records.

These returns have been obtained, in most cases, from the parties immediately connected with the various mines, and from the published ticketing papers. As there is no regular publication of the Lead sales, and as the ores are sold in large and small parcels, sometimes publicly, but often by private contract, there has been much difficulty in obtaining accurate information of the entire produce of the United Kingdom. We have more particularly to acknowledge the very important assistance of Mr. John Taylor, jun., from whose knowledge of the subject the following returns acquire a value for correctness, and a close approximation to the absolute quantities of lead ore raised, and lead smelted, which they would not otherwise possess.

We are also highly indebted for the promptitude with which returns and information have been furnished by Messrs. Walker, Mr. Sopwith, Mr. James Barker, of Bakewell, Mr. Percival Johnson, Mr. Davy, of Redruth, Messrs. Williams, of Scorrier, Mr. Pattinson, and Mr. Hodgson, of Arklow. It being desirable that correct accounts of all the mines of lead and silver should be regularly published, it is hoped that the several parties who are connected with lead mines and smelting works, will furnish to the Mining Record Office the returns for the present year as early in 1848 as possible.

It would appear, from the inquiries which have been made, that the produce of merchantable lead from the ore throughout the kingdom averages about 68 per cent., and that from 7 to 8 ounces of silver is the average quantity at present procured from the ton of lead. In many instances the quantity of lead ore raised has alone been furnished us, in others only the amount of lead smelted; in both cases we have computed, with as much care as possible, the lead and the lead ore.

Table, showing the Total Quantity of Lead Ore raised and Lead smelted in the United Kingdom.

—	LEAD ORE.		LEAD.	
	1845	1846	1845	1846
	Tons.	Tons.	Tons.	Tons.
England . . .	56,479	54,467¾	38,401	36,718
Wales	16,412	14,978¼	11,014½	10,027½
Scotland . . .	1,173	1,161	901	942
Ireland . . .	1,944	1,641	855½	811
Isle of Man . .	2,259	2,316	1,523	1,663
Total . .	78,267	74,564	52,695	50,161½

PRODUCE of LEAD ORE and LEAD in the UNITED KINGDOM for the Years 1845 and 1846.

COUNTY.	MINES.	Lead Ore Returns. 1845	Lead Ore Returns. 1846	Lead Returns. 1845	Lead Returns. 1846
ENGLAND.		Tons.	Tons.	Tons.	Tons.
Cornwall . . .	Callington	950	1,138	570	683
	Huel Mary Ann . . .	..	166	..	100
	Cornubian	420	..	252	..
	East and West Haven .	16	..	9	..
	Huel Trelawney . . .	280	529	168	316
	Camelford	180	..	108	..
	East Huel Rose . . .	7,883	5,191	4,729	3,114
	Cargol	55	306	33	183
	Oxnams	..	188	..	113
	Huel Rose.	57	375	34	224
	,, Penrose. . . .	116	11	69	7
	Holmbush	..	12	..	7
	New Quay	73	..	43	..
	Porthleven	80	82	48	49
	Pentire	..	34	..	20
	Cubert	..	136	..	81
	Leman	..	30	..	18
	Huel Concord	..	30	..	18
Devonshire . .	Tamar	1,454	1,182	944	768
	Huel Betsey	296	58½	148	29
	Huel Adams	59	33	29	16
	East Tamar Consols . .	..	114	..	74
	Combmartin	174	213	104	127
Cumberland . .	Alston Moor Mines . .	6,837	6,418	4,615	4,330
	Roughtingill	175	..	87	..
	Driggith Beck Waste .	21	3¾	10	2
	Dry Gill Mine	..	12½	..	6
	Driggeth Mine	74	36	37	18
	Cumberland	25	..	12	..
	Greensides	1,430	1,560	1,100	1,200
Durham and Northumberland .	Mr. Beaumont's Mines .	12,200	12,000	8,130	8,000
	Teesdale Mines	2,572	2,850	1,688	1,870
	Weardale Ditto	560	560	372	372
	Sharnberry (Durham) .	88	64	58	42
	Derwent Mines	1,626	1,470	988	997
Westmoreland .	Dreftom . . . . . . Hilton	480	480	320	320
Derbyshire . .	Sundry Mines.	8,571	7,571	6,000	5,300
Shropshire . .	Snailbeach	3,000	3,852	2,100	2,700
	Grits and Gravel. . .	300	298	220	219
	Bog Mine	220	230	150	155
	Pennerly	31	100	23	65
	Round Hill	..	11	..	8
Somersetshire .	Mendip Hills	..	4	..	3
Yorkshire . . .	Swale Dale . . . . . Arkendale	4,257	4,257	3,275	3,275
	Grassington	1,358	1,313	816	788
	Cononley	631	663	414	436
	Pately District	930	886	698	665
	Buckden	..	..	..	..
	Total	56,479	54,467¾	38,401	36,718

Produce of Lead Ore and Lead in the United Kingdom for 1845, 1846—*continued.*

COUNTY.	MINES.	Lead Ore Returns. 1845	Lead Ore Returns. 1846	Lead Returns. 1845	Lead Returns. 1846
	WALES.	Tons.	Tons.	Tons.	Tons.
Cardiganshire .	Lisburne Mines . . .	2,492	2,650	1,623	1,722
	Llancynfelyn	..	4	..	2¾
	Bwlch-yr-esgair . . .	30	..	20	..
	Caenant	10	..	6½	..
	Brynglas	10	..	6½	..
	Cwm-ystwyth . . .	356	588	238	382
	Pen-y-banc	24	..	15	..
	Llewyrnog	48	..	30	..
	Esgair-hir.	41	110	26	71
	Cwm-sebon	197	250	128	168
	Penrhiw	46	..	27	..
	Llanfair	158	242	103	157
	Goginan	1,768	1,558	1,149	1,013
	Gogerddan Mines . .	210	118½	136	77
	Pen-y-cefn	36	46	23	29
	Tal-y-bont	25	..	16	..
	Nant-y-creiau	120	57¼	72	33
	Cefn-cwm-brwyno . .	72	75	43	45
	Llwyn-malys	60	..	39	..
	Bwlch-cwm-erfin . . .	23	20	15	13
Carnarvonshire .	Llanrwst	..	113	..	67
Carmarthenshire .	Nant-y-mwyn. . . .	622	659	404	427
	Llanfurnach	15	..	9½	..
Denbighshire . .	Llangollen	..	26	..	17
Flintshire . . .	Tarlargoch	1,955	1,308	1,319	882
	Fron-fownog	125	33	87	23
	Hendre	594	918	416	642
	Longley	230	55	161	38
	Maes-y-safn	1,069	1,296	750	907
	Pen-yr-henblas . . .	822	911	575	637
	Gayer	18	..	12	..
	Mold Mines	1,078	296	726	198
	Long Rake	76	81	51	54
	Milwr	330	139	223	94
	Pen-y-bryn	156	31	109	22
	Dingle and Deep Level .	790	517	553	361
	Pant-y-pwllgwr . . .	..	18	..	12
	Parry's Mine	143	132½	99	92
	Trelogan	94	25	63	17
	Westminster Mines . .	967	819	676	573
	Wainlas	34	35	24	24
	Halkin Hall	133	118	92	81
	Pantyrhys	..	12	..	8
	Carreg-y-boeth . . .	..	11	..	7¾
	Afon-gôch.	..	62	..	40
	Bodle-wyddan	..	25	..	17
	Belgrave	..	305	..	213
	Brintail	45¼	84½	31	59
	Tyddyn-gwydd . . .	57	..	40	..
	Bryngwriog	103	27	72	19
	Holywell	16	..	10	..
	Maes-lygan	37	..	24	..
	Jamaica	..	33	..	21
	Mines under 10 Tons .	147	168	94	109
	Carried forward . .	15,382¼	13,966¾	10,336½	9,374½

Produce of Lead Ore and Lead in the United Kingdom for 1845, 1846—*continued.*

COUNTY.	MINES.	Lead Ore Returns. 1845	Lead Ore Returns. 1846	Lead Returns. 1845	Lead Returns. 1846
		Tons.	Tons.	Tons.	Tons.
	Brought forward . .	15,382¼	13,966¾	10,366½	9,374½
Montgomeryshire	Llangynnog	115	103	74	66
	Delife	586	557	383	361
	Cae-Conroy	73	34	47	22
	Rhos-wydol	..	52½	..	34
	Dwngwm	25	..	16	..
	Gorn	33	43	21	28
	Pantmawr.	48	..	29	..
	Nant Iago	..	20	..	12
	Craig-Rhiwarth . . .	..	30	..	20
	Brin-dail	130	150	96	110
Merionethshire .	Portmadoc	20	..	12	..
	Total	16,412¼	14,978¼	11,014½	10,027½
	IRELAND.				
Clare	Kilbricken	102	38	66	25
	Ballyhicky	119	32	83	22
Down	Newtonards	433	211	280	137
	Conlig	100	65	65	42
Limerick . . .	Limerick	12	..	8½	..
Monaghan . .	Bond and Newry . .	21	44	13	29
Wicklow . . .	Glenmalure	367	314	270	250
	Sundry Mines. . . .	93	240	56	144
	Luganure	457	405	..	..
Waterford . .	Barristown	22	250	14	162
Wexford . . .	Caime	218	42	..	..
	Total	1944	1641	855½	811
	ISLE OF MAN.				
ISLE OF MAN . .	Foxdale Mines, including Peel's Shipment and Beckwith's Vein . .	1,902	2,071	1,283	1,498
	Laxey	327	155	220	104
	Douglas	..	80	..	54
	Mona	30	10	20	7
	Total	2,259	2,316	1,523	1,663
	SCOTLAND.				
Ayrshire . . .	Wood Head	509	480	424	400
Dumbartonshire .	Dumbarton	269	..	161	..
Kirkcudbrightshire	Cuernsmore	..	20	..	13
Lanarkshire . .	Lead Hills Mine . . .	395	661	316	529
	Total	1,173	1,161	901	942

Lead Ore and Lead Imported and Exported.

Years.	IMPORTED. Lead Ore. Tons.	Cwts.	IMPORTED. Lead. Tons.	Cwts.	EXPORTED. Lead Ore. Tons.	Cwts.	EXPORTED. Lead. Tons.	Cwts.
1843 . . .	68	16	2,775	0	176	9	14,610	14
1844 . . .	95	9	3,058	0	257	3	14,697	0
1845 . . .	444	3	5,209	17	169	1	10,485	8
1846 . . .	724	1	7,862	12	53	13	6,421	15

Produce of Lead Ore and Lead in the United Kingdom for the Year 1847. Robert Hunt, Keeper of Mining Records.

COUNTY.	MINES.	Lead Ore Returns.	Lead Returns.
	England.	Tons.	Tons.
Cornwall	Callington	1,249	824
	Huel Mary Ann	192	139
	Huel Trelawney	883	640
	Huel Trehane	312	206
	Herodscoombe	37	20
	Herodsfoot	375	300
	East Huel Rose	6,424	3,854
	North Huel Rose	84	50
	Cargol	951	570
	Oxnams	47	28
	Huel Rose	378	227
	Cubert	354	212
	Holmbush	60	36
	Leman	73	44
	Great Callestock Moors . .	109	64
	*Huel Concord	30	18
	Callestock	116	72
Devonshire . . .	Tamar	1,082	649
	Huel Betsey	7	3½
	Huel Adams	250	150
	East Tamar Consols . . .	130	78
	Combmartin	202	121
	Sundry Mines under 10 Tons	50	25
Cumberland . . .	Alston Moor Mines	6,385	4,470
	Roughtingill	. .	. .
	Driggith Beck Waste . . .	48	24
	Dry Gill Mine	14	8
	Cumberland	. .	. .
	Greensides	1,560	1,200
Durham and Northumberland . .	East and West Allendale, and Weardale	13,600	9,300
	*Teesdale Mines	3,850	2,538
	*Sharnberry	64	42
	Derwent Mines	1,674	1,033
Westmoreland . .	*Dreftom . . . . *Hilton	480	320
Derbyshire . . .	Sundry Mines	7,150	4,250
Shropshire . . .	Snailbeach	3,486	2,440
	Grits and Ba-tholes	300	210
	Bog Mine	100	70
	Pennerly	70½	49
	Round Hills	. .	. .
Somersetshire . .	Mendip Hills	. .	. .
Yorkshire . . .	Swale Dale . . . . Arkendale	4,200	3,200
	Grassington	1,546	922
	Cononley	692	441
	Pately District.	1,000	660
	Total	59,614½	39,507½

Produce of Lead Ore and Lead in the United Kingdom for the Year 1847—*continued.*

COUNTY.	MINES.	Lead Ore Returns.	Lead Returns.
	WALES.	Tons.	Tons.
Cardiganshire	Lisburne Mines	2,028	1,338
	Cwm-ystwyth	439	263
	Esgair-hir	45	27
	Cwm-sebon	205	123
	Llanfair	291	189
	Goginan	1,446	951
	Gogerddan Mines, Bog and Daren	194	128
	Nant-y-creiau	79	48
	Pen-y-bont-pren	15	7½
	Cefn-cwm-brwyno	36	24
	Llwyn-malys	49	32
	Bwlch-cwm-erfin, Bwlch-Consols	45	30
	Pen-y-bont-pren	27	16
Carnarvonshire	Llanrwst	54	32
Carmarthenshire	Nant-y-mwyn	429½	284
Denbighshire	Llangollen	..	..
Flintshire	Tarlargoch	964	674
	Fron-fownog	1,219	884
	Hendre	1,160	838
	Longley	0	0
	Maes-y-safn	1,136	823
	Penrhynblas	936	655
	Mold Mines	190	133
	Long Rake	52	36
	Milwr	88	61
	Pen-y-bryn	40	28
	Dingle and Deep Level	688	498
	Parry's Mine	51	37
	Trelogan	0	0
	Westminster Mines	1,040	754
	Halkin Hale	49	35½
	Carreg-y-boeth	45	32
	Afon-goch	11	8
	Bodle-wyddan	25	17½
	Belgrave	328	230
	Brintail	100	70
	Bryngwriog	30	21
	Holywell	0	0
	Jamaica	602	433½
	Mines under 10 Tons	150	105
	Bwlchyddaufryn	56	39
	Bwlch-y-plwn	14	10
	Sundries under 10 Tons	2,500	1,700
Montgomeryshire	Llangynnog	105	63
	Delife	524	212½
	Cae-Conroy	34	20½
	Rhos-wydol	66	40
	Dwngwm	47	28
	Craig-Rhiwarth	46	28
	Brintail and Penclyn	158	100
Merionethshire	Nantmelyn	11	6½
	Barmouth	35	21
	Cowarch	174	104½
	Caermynydol	22	13
	Paencryn	32	19
	Carried forward	18,110½	12,271

Produce of Lead Ore and Lead in the United Kingdom for the Year 1847—*continued.*

COUNTY.	MINES.	Lead Ore Returns.	Lead Returns.
		Tons.	Tons.
Merionethshire—*cont.*	Brought forward . . .	18,110½	12,271
	Panty-kelyn	12	8
	Panty-cher	25	15
	Total	18,147½	12,294
	IRELAND.		
Clare	Kilbricken	96	67
	Ballyhicky	..	..
Down	Newtownhards	410	246
	Conlig	347	208
Limerick . . .	Shallee	209	125
Monaghan . . .	*Bond and Newry	44	29
Wicklow . . .	Glenmalure	120	72
	Luganure	724	434
Waterford . . .	Barristown	301	199
Wexford	Caime	0	0
	Total	2,251	1,380
	SCOTLAND.		
Ayrshire	*Wood Head	480	400
Argyleshire . . .	Strontian Mines	50	30
Dumbartonshire .	Dumbarton	..	..
Kirkcudbrightshire .	Caernsmore	354	212½
Lanarkshire . . .	Lead Hills Mine	275	180
Dumfrieshire . .	Wanlock head	0	0
	Total	1,159	822½
	ISLE OF MAN.		
Isle of Man . . .	Foxdale Mines, including Peel's Shipment, &c. . .	2,040	1,346
	Laxey	375	247½
	Douglas	160	105½
	Mona	0	0
	Total	2,575	1,699

TABLE showing the TOTAL QUANTITY of LEAD ORE raised and LEAD smelted in the United Kingdom in 1847.

	Lead Ore.	Lead.
	Tons.	Tons.
England	59,614½	39,507½
Wales	18,147½	12,294
Ireland	2,251	1,380
Scotland	1,159	822½
Isle of Man . . .	2,575	1,699
Total . . .	83,747	55,703

Lead Ore and Lead Imported and Exported during 1847.

Imported.

Lead Ore.				Lead.			
Tons.	Cwts.	qrs.	lbs.	Tons.	Cwts.	qrs.	lbs.
507	8	0	25	3,931	13	3	16

The quantity of this lead retained for home consumption was

Tons.	Cwts.	qrs.	lbs.
216	0	3	5

Of the above quantity,

Tons.	Cwts.	qrs.	lbs.
3,267	11	3	15

were imported from Spain, and the silver being extracted, was nearly all re-shipped.

Exported.

Lead Ore.			Lead.			
Tons.	Cwts.		Tons.	Cwts.	qrs.	lbs.
85	19	Pig and Rolled Lead	8,258	11	3	21
		Shot	1,176	13	1	5
		Litharge	327	13	2	2
		Red Lead	829	14	1	1
		White Lead	1,389	4	2	5

Note.—Of the 7,682 tons imported in 1846, 4,700 tons were again exported after the silver had been extracted.

From those mines marked * no returns have been received; but the amounts given, which are the same as last year, are very near the truth.

6		MINES.
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TABLE of the Copper produced from the Mines of Cornwall and Devon, during the Years 1845, 1846, and 1847: showing the Ore raised from each Mine, the fine Copper produced, Average Price per Ton, Amount in Money, Produce per Cent. of the Ore, and the average Standard.—ROBERT HUNT, Keeper of Mining Records.

1845

MINES.	Ore. Tons.	Copper. Tons. cwts. qrs. lbs.	Average Price per 21 Cwt. £. s. d.	Amount. £. s. d.	Produce. Per Cent.	Standard.
Huel Maria	11,288	1,154 6 2 26	10 3 0	100,971 15 0	13¼	88·18
United Mines	14,374	1,012 3 2 10	5 0 6	74,908 1 6	7	113·1
Consolidated Mines	8,798	685 14 1 20	5 8 6	51,146 13 0	7¾	109·17
Carnbrea	6,674	532 9 3 21	5 4 0	39,462 14 0	8	108·11
Fowey Consols	8,976	751 15 1 12	5 1 6	49,233 0 6	8⅜	98·6
North Roskear	6,130	513 11 3 26	5 17 6	40,955 10 6	8⅜ 1/16	107·17
East Huel Crofty	6,173	483 4 1 14	5 14 0	36,302 14 6	7⅞ 1/16	110·5
West Caradon	4,157	475 0 2 0	7 4 0	33,272 1 0	10⅜	95·16
Tincroft	5,644	412 5 0 23	5 0 6	30,627 10 6	7¼	111·18
Par Consols	5,655	464 10 0 26	4 16 6	30,881 5 6	8¼	99·19
Huel Prosper, &c.	5,993	406 4 1 16	4 14 0	29,143 19 6	6¾	112·6
Tresaveau	6,683	375 18 3 24	4 1 6	26,194 4 0	5⅝	118·11
South Caradon	4,631	394 15 0 12	5 16 0	27,266 9 6	8½	101·6
,, Huel Basset	3,390	267 5 2 8	6 4 6	19,961 16 0	7⅞	109·11
Dolcoath	3,504	233 14 0 25	4 18 0	16,996 16 6	6⅝	113·19
Trenow Consols	2,306	257 2 1 25	8 11 6	19,565 14 0	11⅛	100·13
Huel Providence	2,615	205 14 3 17	5 10 0	14,749 17 0	7⅞	106·13
Holmbush	1,887	208 2 1 19	7 9 0	14,957 5 6	11	96·16
United Hills, &c	3,348	201 4 1 15	4 2 6	14,154 0 6	6	116·2
Camborne Vean, &c.	2,751	185 9 0 20	4 10 0	13,873 2 6	6¾	115·12
Poldice	2,485	153 3 0 1	4 11 0	10,889 5 6	6⅛	115·14
Hallenbeagle	2,879	152 9 3 17	4 3 0	10,478 18 6	5¼	120·13
Trethellen	2,612	143 5 2 23	3 14 0	9,978 17 0	5½	119·15
Huel Seton	2,035	148 13 3 18	5 2 0	11,352 6 0	7¼	114·
,, Lydia, &c	2,267	136 13 2 5	3 18 6	9,652 14 6	6	116·5
Bedford United Mines	1,297	125 3 3 26	6 16 6	8,744 1 6	9⅝	98·7
Botallack	1,274	140 13 1 12	8 19 0	9,656 10 6	11	93·11
Treleigh Consols	1,637	123 0 3 2	5 2 0	9,269 15 0	7½	111·19
West Huel Jewel	1,883	113 13 0 16	4 9 0	8,015 1 6	6	116 7
South Roskear, &c.	1,464	113 18 2 4	5 6 6	8,758 0 6	7¾	112 1
Grambler and St. Aubyn	1,494	112 2 0 15	5 7 0	8,201 14 0	7½	109·16
Huel Jewell	1,476	109 5 2 5	5 7 6	7,892 17 0	7⅜	109·7
Levant	1,088	106 11 0 7	6 15 0	7,154 19 6	9¾	95·4
Perran St. George	1,665	105 4 2 15	3 15 0	7,322 16 0	6¼ 1/16	113·2
Lanivet Consols	1,125	91 11 0 5	5 0 0	6,081 14 6	8⅛	100·4
Godolphin	852	101 19 1 17	9 15 0	7,715 5 0	12	98·13
Tresaven Barrier	874	83 2 0 5	7 1 0	6,055 0 0	9½	101·15
Treviskey	767	82 1 2 27	8 4 0	6,436 4 6	10⅝ 1/16	104·2
Huel Brewer	1,142	78 12 1 13	4 18 0	5,765 16 0	6⅞	113·6
,, Buller	1,313	76 3 1 10	4 11 6	5,211 12 6	5¾	115·17
East Pool	929	73 5 1 4	6 1 0	5,430 4 0	7⅞	108·19
Huel Trewavas	977	73 2 3 16	5 11 0	5,452 10 0	7½	111·6
,, Ellen	714	57 17 2 23	5 9 6	4,373 0 6	8⅛	109·10
Tretoil	658	51 9 2 1	4 11 6	3,499 15 6	7¾ 1/16	103·3
Penstruthal	534	45 1 1 16	6 10 6	3,344 15 6	8⅜	106 16
Creegbraws	546	39 1 0 6	4 3 0	2,402 7 0	7¼	112·15
Huel Harriet	689	41 1 3 8	3 17 0	2,941 10 6	5⅞ 1/16	117·16
,, Virgin	655	41 13 3 9	4 13 0	2,964 5 6	6⅜	114·8
,, Sisters	577	37 4 1 13	..	2,595 6 0	6⅜ 1/16	112 8
,, Darlington	649	35 5 0 9	3 12 6	2,397 8 6	5⅜	118·12
,, Maiden	484	32 7 3 16	4 18 6	2,333 3 0	6⅝	113·5
Cook's Kitchen	502	24 4 2 4	2 15 0	1,522 8 6	4¾ 1/16	119·18
Providence Mines	433	31 6 0 2	5 1 6	2,325 13 6	7¼	112·6
North Downs	306	24 0 1 13	5 16 0	1,731 0 6	7¾ 1/16	107·3
Huel Clifford	348	29 10 0 6	7 1 0	2,254 0 6	8½	108·16
,, Prudence	513	24 1 0 26	2 16 0	1,477 4 0	4⅝ 1/16	120·
,, Gorland	366	23 2 0 22	4 1 0	1,652 8 6	6¼	115·1
,, Vyvyan	378	22 4 3 8	4 1 6	1, 62 18 6	5⅞	112·14
,, Busy	420	16 8 2 18	2 5 0	988 12 0	3⅞	130·13
,, Trenwith	203	21 3 2 9	7 18 0	1,535 2 6	10⅜	98·19
,, St. Andrew	370	14 18 2 0	2 5 6	826 6 0	4	123·13
West Huel Treasury	267	17 16 2 26	4 2 0	1,274 7 0	6⅝	112·16
Williams' East Downs	242	16 3 3 17	4 16 6	1,160 18 0	6⅝	113·1
West Trethellan	295	15 8 3 6	3 15 6	1,067 14 0	5¼	121·18
South Huel Francis	249	14 8 3 8	4 12 0	979 12 0	5¾	115·11
Huel Alice, &c.	154	13 16 2 23	5 12 6	1,033 18 6	9	105 11
,, Anna	215	11 15 0 13	3 6 0	822 16 0	5½	120·6
,, Andrew and Nanjiles	166	12 18 3 6	..	993 12 0	7¾	112·8
North Pool	217	10 16 1 0	..	788 9 0	5	128·4
West Fowey Consols	169	11 10 2 8	4 4 6	739 8 0	6¾	104·13
Condurrow	166	10 14 3 19	4 10 0	785 13 6	6¼ 1/16	116·1
Huel Henry	148	10 5 1 18	5 0 6	750 6 6	6⅞	112·17
Copper House Slag	218	9 2 1 4	..	332 2 0	4⅛	102·7
Harvey's Dross	211	8 14 3 24	1 16 6	314 13 0	4⅛	102·15
Mark Valley	165	7 15 2 0	..	521 17 6	4⅝ 1/16	125·16
Carn Perran	158	8 0 2 17	3 13 0	518 1 6	5 1/16	119·
Huel Rodney	132	7 0 0 27	..	465 6 0	5¼	118 5
,, Comfort	122	5 3 2 12	3 4 0	313 9 6	4¼	125·16
Ting Tang Consols	100	5 17 2 0	..	402 10 0	5⅞	115·
East Huel Friendship	..	..	..	..	..	..
St. Agnes Consols	..	..	..	..	..	..
Huel Kayle	..	..	..	..	..	..
North Huel Basset	..	..	..	..	..	..
Hanson Mines	..	..	..	..	..	..
Pempolls and Co.'s Regulus	..	..	..	..	..	..
Huel Alfred Consols	..	..	..	..	..	..
,, Bucketts	..	..	..	..	..	..
Redruth Consols	..	..	..	..	..	..
St. Austle Consols	..	..	..	..	..	..
Charles Town United	..	..	..	..	..	..
Huel Agar	..	..	..	..	..	..
Wellington Mines	..	..	..	..	..	..
South Tolgus	..	..	..	..	..	..
East Seton	..	..	..	..	..	..
Huel Mary Consols	..	..	..	..	..	..
,, Ruby	..	..	..	..	..	..
Gwinear Consols	..	..	..	..	..	..
Huel Jane	..	..	..	..	..	..
South Huel Fortune	..	..	..	..	..	..
Great Work	..	..	..	..	..	..
Huel Tryphena	..	..	..	..	..	..
East Relistian	..	..	..	..	..	..
Sundry Small Mines	706	48 18 3 2	4 15 6	3,391 11 0	6⅞	109·1
	162,557	12,883 3 1 25	..	919,934 6 0	7⅞	106·2

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MINES.	Ore. Tons.	Copper. Tons. cwts. qrs. lbs.	Average Price per 21 Cwt. £. s. d.	Amount. £. s. d.	Produce. Per Cent.	Standard.
Huel Maria	15,684	1,578 7 0 18	7 4 0	95,469 10 6	10 1/16	90·5
United Mines	11,956	802 12 1 0	5 1 6	56,471 2 6	6¾	110·17
Consolidated Mines	9,057	746 1 1 24	6 1 6	54,386 2 6	8¼	105·19
Carnbrea	7,288	600 2 0 3	6 6 6	41,477 6 0	8¼	102·4
Fowey Consols	7,189	572 15 2 4	5 9 6	34,760 16 0	8	95·16
North Roskear	5,052	396 1 0 23	6 8 6	29,207 12 0	7¾ 1/16	108·9
East Huel Crofty	4,127	312 8 2 18	5 13 6	22,698 13 0	7½ 1/16	108·12
West Caradon	4,736	503 18 0 10	7 7 0	32,801 2 6	10⅝	91·8
Tincroft	5,550	364 11 3 27	5 5 6	24,897 3 6	6½ 1/16	109·15
Par Consols	6,065	557 12 3 27	5 13 0	35,144 4 0	9⅛ 1/16	92·18
Huel Prosper, &c.	3,589	252 6 1 15	4 17 0	17,509 10 0	7	107·16
Tresaveau	5,855	329 9 2 24	3 16 6	22,007 5 6	5⅝	115·4
South Caradon	4,159	382 18 0 4	5 19 6	24,739 16 0	9¼ 1/16	95·
,, Huel Basset	2,911	211 2 2 7	7 11 0	14,920 19 6	7¼	108·5
Dolcoath	2,156	138 12 2 11	4 13 0	9,546 9 0	6⅜	111·4
Trenow Consols	1,786	166 0 1 16	7 14 0	11,845 4 0	9¼	100·13
Huel Providence	1,105	92 15 2 0	6 7 6	6,296 2 6	8⅜	99·19
Holmbush	1,279	123 4 3 10	7 10 6	8,118 0 0	9⅝	94·18
United Hills, &c	3,431	206 7 2 1	4 2 0	13,759 11 0	6	111·19
Camborne Vean, &c.	3,161	213 14 1 14	5 3 0	15,608 7 0	6⅞	110·15
Poldice	1,985	124 7 3 22	4 9 6	8,563 16 0	6¼	112·6
Hallenbeagle	1,291	62 9 2 16	3 4 6	4,000 10 0	4⅞	120·5
Trethellen	1,517	77 9 0 19	3 14 6	5,118 1 6	5⅛	119·8
Huel Seton	4,590	408 13 0 10	6 6 6	30,160 3 0	8⅞	104·8
,, Lydia, &c	1,460	86 19 3 22	4 5 6	5,839 5 0	5⅞ 1/16	113·5
Bedford United Mines	1,158	108 17 2 5	6 10 0	6,960 18 6	9⅜	93·13
Botallack	513	52 16 3 9	6 15 0	3,338 2 0	10¼	91·5
Treleigh Consols	2,151	169 9 1 23	6 1 6	12,190 13 0	7⅞	106·10
West Huel Jewel	1,520	88 8 1 12	4 3 0	5,908 13 6	5¾ 1/16	113·13
South Roskear, &c.	1,376	95 15 1 19	5 9 0	6,952 6 6	6⅞ 1/16	111·15
Grambler and St. Aubyn	1,292	94 5 3 23	5 7 0	6,628 1 0	7¼	107·19
Huel Jewell	844	57 17 0 0	5 2 6	4,035 6 0	6⅞	109·10
Levant	1,293	130 6 2 18	6 10 6	8,199 18 6	10 1/16	91·13
Perran St. George	1,782	126 14 1 8	4 15 0	8,522 8 6	7⅛	106·12
Lanivet Consols	1,159	100 17 1 1	5 14 0	6,235 1 6	8⅝ 1/16	95·14
Godolphin	635	48 13 2 20	7 11 0	3,330 0 0	7⅝	103·11
Tresaven Barrier	430	29 19 0 5	5 4 6	2,046 3 0	6⅞ 1/16	107·8
Treviskey	885	89 14 1 1	8 9 0	6,623 3 6	10⅛	100·14
Huel Brewer	432	21 8 0 26	4 13 6	1,348 1 0	4⅞ 1/16	117·19
,, Buller	343	17 4 2 22	3 8 6	1,091 17 0	5	117·9
East Pool	633	43 15 1 8	5 16 0	3,009 7 6	6⅞	108·4
Huel Trewavas	397	33 7 2 21	5 15 6	2,330 14 6	8⅜	101·11
,, Ellen	743	61 19 1 0	6 8 0	4,466 12 6	8¼ 1/16	104·15
Tretoil	569	38 14 3 18	5 0 6	2,344 8 6	6¾	103·15
Penstruthal	165	13 0 1 19	5 18 6	926 16 0	7⅞	105·16
Creegbraws	817	59 10 1 17	5 11 6	4,297 15 0	7¼	109·19
Huel Harriet	987	60 2 2 3	4 10 0	4,200 5 6	6⅛	114·10
,, Virgin	946	72 2 3 23	5 1 6	4,956 15 6	7⅝	104 1
,, Sisters	910	68 0 1 17	4 7 0	4,375 6 6	7½	101·16
,, Darlington	..	..	..	..	..	..
,, Maiden	361	21 11 3 21	4 1 0	1,456 10 0	6	112·19
Cook's Kitchen	134	7 4 1 24	4 0 6	468 12 6	5⅜	115·14
Providence Mines	222	11 10 2 19	4 9 0	683 11 0	5⅛ 1/16	108·2
North Downs	232	17 19 0 8	5 1 6	1,284 7 0	7¾	106·14
Huel Clifford	345	24 7 3 19	5 15 6	1,790 16 0	7 1/16	111·11
,, Prudence	..	..	..	..	..	..
,, Gorland	144	9 19 1 3	4 10 0	676 19 6	6⅞	107·8
,, Vyvyan	300	18 9 2 7	3 19 0	1,108 1 6	6⅛	103·13
,, Busy	231	10 2 1 20	2 5 0	513 4 6	4⅜	116·12
,, Trenwith	79	6 18 3 8	8 0 0	485 16 0	8¾	99·14
,, St. Andrew	..	..	..	..	..	..
West Huel Treasury	483	35 2 2 7	4 13 6	2,444 9 0	7¼	106·12
Williams' East Downs	139	10 4 0 1	5 0 0	721 19 6	7¼ 1/16	107·16
West Trethellan	137	6 13 2 10	3 7 0	431 5 0	4⅞	120·
South Huel Francis	903	127 3 3 21	7 11 0	0,368 4 0	14 1/16	92·19
Huel Alice, &c.	..	..	..	..	..	..
,, Anna	..	..	..	..	..	..
,, Andrew and Nanjiles	382	29 6 0 18	5 18 6	2,087 17 0	7⅝	106·9
North Pool	211	12 14 3 10	3 1 0	783 14 0	4⅝	123·12
West Fowey Consols	130	10 1 2 22	4 8 6	601 7 0	7¾	95·10
Condurrow	609	36 0 3 17	4 6 6	2,395 9 6	5⅞	112·9
Huel Henry	..	..	..	..	..	..
Copper House Slag	158	7 13 0 0	1 10 6	306 18 0	4¾ 1/16	98·8
Harvey's Dross	226	12 6 0 5	2 1 6	558 16 0	5⅜ 1/16	97·6
Mark Valley	853	41 8 2 27	3 0 0	2,583 10 6	4⅞	114·15
Carn Perran	197	10 5 2 11	3 6 6	645 3 0	5¼	114·13
Huel Rodney	407	24 3 2 24	3 10 6	1,548 11 0	5⅞ 1/16	109·7
,, Comfort	267	16 4 0 19	3 13 6	1,058 0 6	6 1/16	110·3
Ting Tang Consols	414	24 13 3 5	3 18 0	1,643 14 0	6	112·3
East Huel Friendship	1,135	138 19 3 5	7 18 6	8,994 17 0	12¼	87·19
St. Agnes Consols	527	24 15 0 20	3 7 0	1,491 9 6	4⅝ 1/16	116·13
Huel Kayle	237	20 6 0 27	5 5 0	1,3-3 5 6	8½ 1/16	99·13
North Huel Basset	226	16 12 2 27	5 7 6	1,131 2 0	7⅜	104·17
Hanson Mines	162	10 18 0 1	5 10 0	747 13 6	6¾	107·17
Pempolls and Co.'s Regulus	105	10 12 0 0	..	776 10 0	10⅛	98·13
Huel Alfred Consols	147	10 9 2 14	4 14 0	744 6 6	7¼	108·19
,, Bucketts	119	8 2 1 23	4 10 0	560 0 6	6¾	109·10
Redruth Consols	71	6 19 2 16	8 2 0	511 1 0	9⅞	100·17
St. Austle Consols	75	5 0 3 8	4 7 0	318 15 6	6¾	106·18
Charles Town United	..	..	..	..	..	..
Huel Agar	..	..	..	..	..	..
Wellington Mines	..	..	..	..	..	..
South Tolgus	..	..	..	..	..	..
East Seton	..	..	..	..	..	..
Huel Mary Consols	..	..	..	..	..	..
,, Ruby	..	..	..	..	..	..
Gwinear Consols	..	..	..	..	..	..
Huel Jane	..	..	..	..	..	..
South Huel Fortune	..	..	..	..	..	..
Great Work	..	..	..	..	..	..
Huel Tryphena	..	..	..	..	..	..
East Relistian	..	..	..	..	..	..
Sundry Small Mines	1,021	66 2 0 19	4 5 0	4,181 2 0	6½	105·14
	150,431	11,850 14 1 1	..	796,182 6 6	7⅞	102·1

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MINES.	Ore. Tons.	Copper. Tons. cwts. qrs. lbs.	Average Price per 21 Cwt. £. s. d.	Amount. £. s. d.	Produce. Per Cent.	Standard.
Huel Maria	14,175	1,474 11 1 6	6 7 0	95,873 1 6	10⅜	93·17
United Mines	12,888	864 12 3 8	4 17 6	61,026 15 0	6¾ 1/16	111·3
Consolidated Mines	9,849	812 1 2 16	6 0 6	59,122 0 6	8¼	105·16
Carnbrea	10,372	1,028 16 0 13	6 5 0	73,445 8 0	9⅞ 1/16	98·17
Fowey Consols	6,726	574 17 3 17	5 3 6	38,820 15 0	8½	100·5
North Roskear	5,773	459 11 2 1	5 17 0	33,480 5 6	8	107·1
East Huel Crofty	3,580	273 0 2 20	5 15 0	19,540 16 6	7⅝	107·6
West Caradon	4,135	413 18 0 15	7 2 0	29,056 1 6	10	98·3
Tincroft	5,473	333 1 1 7	4 8 6	22,371 12 6	6⅛	111·19
Par Consols	6,101	625 10 1 5	6 6 0	42,953 5 0	10¼	95·9
Huel Prosper, &c.	3,257	207 0 1 1	4 17 0	14,348 0 6	6⅜	111·8
Tresaveau	4,588	291 3 1 27	4 3 0	20,271 14 0	6¼ 1/16	112·11
South Caradon	4,570	410 3 3 19	6 10 6	30,679 0 6	9⅛	98·15
,, Huel Basset	1,648	133 7 1 26	5 2 0	9,469 2 0	8⅛ 1/16	104·13
Dolcoath	2,057	135 8 3 26	4 18 6	9,414 16 6	6½ 1/16	110·17
Trenow Consols	433	32 13 1 13	5 17 0	2,412 4 6	7½	110·
Huel Providence	876	73 18 0 23	..	5,201 3 0	8⅜ 1/16	102·7
Holmbush	802	70 16 2 8	6 4 0	4,845 9 6	8¾ 1/16	100·1
United Hills, &c	3,388	209 1 3 9	4 3 6	14,414 13 6	6¼ 1/16	113·1
Camborne Vean, &c.	3,297	229 10 2 1	5 1 6	16,289 17 0	6⅞ 1/16	110·2
Poldice	1,873	121 2 1 14	4 4 6	8,547 12 6	6⅜ 1/16	112·14
Hallenbeagle	..	..	..	..	..	..
Trethellen	1,304	65 5 2 15	3 8 0	4,313 15 6	5	120 9
Huel Seton	5,402	451 10 0 3	6 9 6	33,012 16 6	8⅜	105·14
,, Lydia, &c	161	9 17 0 25	..	645 15 0	6⅛	110·1
Bedford United Mines	1,355	148 8 1 22	6 2 0	10,239 13 6	10⅞ 1/16	94·11
Botallack	251	23 17 0 20	5 17 0	1,551 1 0	9½	95·11
Treleigh Consols	2,308	217 18 1 25	6 10 0	16,213 16 6	9⅜ 1/16	103·5
West Huel Jewel	975	57 3 1 5	3 16 6	3,875 10 0	5⅞	114·6
South Roskear, &c.	756	58 2 2 2	5 7 6	4,210 13 0	7⅝ 1/16	107·16
Grambler and St. Aubyn	1,201	84 0 1 5	5 16 0	5,921 2 6	7	109·9
Huel Jewell	806	57 11 3 14	4 17 0	4,065 8 0	7⅛	108·14
Levant	851	98 16 3 13	7 15 0	6,849 1 6	11⅝	94·5
Perran St. George	2,053	121 1 2 3	4 10 6	8,030 8 6	5⅞	114·
Lanivet Consols	1,126	82 10 3 8	5 5 6	5,312 11 0	7¼ 1/16	104·11
Godolphin	..	..	..	..	..	..
Tresaven Barrier	545	44 13 1 1	4 13 0	3,193 0 6	8⅛ 1/16	104·15
Treviskey	2,162	198 11 2 23	7 11 6	14,678 9 6	9⅛ 1/16	103·11
Huel Brewer	465	17 8 3 22	2 11 6	1,016 6 0	3¾	130·17
,, Buller	..	..	3 2 6	..	..	..
East Pool	608	34 2 1 11	4 0 0	2,188 13 6	5⅝	112·15
Huel Trewavas	..	..	..	..	..	..
,, Ellen	614	57 0 2 0	6 0 0	4,129 7 0	9¼	101·15
Tretoil	328	20 10 2 22	4 3 6	1,326 3 6	6¼	111·12
Penstruthal	..	..	..	..	..	..
Creegbraws	1,314	86 10 1 8	4 16 6	5,984 1 6	6½ 1/16	110·19
Huel Harriet	546	30 19 0 4	4 1 6	2,144 14 6	5⅝ 1/16	117·7
,, Virgin	464	30 13 3 16	5 1 0	2,216 6 0	6⅝	113·
,, Sisters	1,134	100 16 0 11	6 11 0	7,341 17 0	8⅞	104·6
,, Darlington	..	..	..	..	..	..
,, Maiden	326	20 2 2 15	4 6 6	1,371 0 0	6⅛ 1/16	112·2
Cook's Kitchen	..	..	..	..	..	..
Providence Mines	..	..	..	..	..	..
North Downs	183	14 10 3 26	5 19 0	1,093 8 6	7⅞ 1/16	109·8
Huel Clifford	409	27 1 0 22	4 19 0	1,922 3 0	6⅝	112·5
,, Prudence	142	6 6 0 6	..	369 2 0	4⅜ 1/16	121 2
,, Gorland	69	5 8 2 26	5 1 6	380 15 0	7⅞	104·7
,, Vyvyan	234	13 1 0 17	3 11 0	813 15 6	5½ 1/16	110·15
,, Busy	184	8 13 3 3	2 18 6	537 11 6	4¾	119·18
,, Trenwith	..	..	..	..	..	..
,, St. Andrew	..	..	..	..	..	..
West Huel Treasury	318	21 15 1 9	5 3 0	1,511 17 0	6¾ 1/16	108·19
Williams' East Downs	..	..	..	..	..	..
West Trethellan	435	20 3 0 25	3 5 6	1,316 5 0	4⅝	124·2
South Huel Francis	2,294	319 16 0 12	11 18 6	23,879 0 0	13⅞ 1/16	94·4
Huel Alice, &c.	..	..	..	..	..	..
,, Anna	..	..	..	..	..	..
,, Andrew and Nanjiles	442	33 10 2 21	5 5 6	2,389 12 6	7½ 1/16	107·2
North Pool	3,096	211 7 3 2	4 10 6	14,660 6 0	6¾ 1/16	109·5
West Fowey Consols	..	..	..	..	..	..
Condurrow	1,235	72 16 0 22	3 18 0	4,905 9 6	5⅞	113·12
Huel Henry	..	..	..	..	..	..
Copper House Slag	..	..	..	..	..	..
Harvey's Dross	..	..	..	..	..	..
Mark Valley	1,016	49 18 0 2	3 7 0	3,251 17 0	4⅞	117·1
Carn Perran	106	7 16 2 13	4 9 0	566 2 6	7⅜ 1/16	108·17
Huel Rodney	724	40 8 2 12	4 2 0	2,690 19 6	5½ 1/16	114·17
,, Comfort	1,436	69 4 1 13	3 14 6	4,507 8 6	4¾ 1/16	121·13
Ting Tang Consols	327	19 2 0 18	4 3 0	1,329 15 0	5¾ 1/16	116·5
East Huel Friendship	2,790	388 2 2 26	7 18 6	22,756 10 6	11¼	92·1
St. Agnes Consols	..	..	..	..	..	..
Huel Kayle	..	..	..	..	..	..
North Huel Basset	569	44 18 0 17	4 18 6	3,164 1 6	7⅞	105·
Hanson Mines	101	6 6 0 4	4 15 0	432 4 6	6¼	111·1
Pempolls and Co.'s Regulus	..	..	..	..	..	..
Huel Alfred Consols	1,660	95 8 3 9	4 14 0	6,477 16 6	5¾	114·16
,, Bucketts	1,281	84 19 2 1	4 10 0	5,935 4 0	6⅝	110·17
Redruth Consols	93	7 13 1 9	6 3 0	559 9 6	8¼	106·5
St. Austle Consols	..	..	..	..	..	..
Charles Town United	198	47 3 0 19	18 6 6	3,615 9 6	23¾ 1/16	88·12
Huel Agar	593	41 18 1 20	4 16 6	2,839 9 6	7 1/16	106·6
Wellington Mines	194	21 16 1 0	6 14 0	1,564 11 0	11¼	96·
South Tolgus	262	20 4 2 10	5 9 0	1,446 13 6	7¾	106·13
East Seton	250	18 12 3 5	5 17 6	1,359 12 6	7⅜ 1/16	109·8
Huel Mary Consols	146	12 18 0 22	..	864 0 0	8¾ 1/16	98·13
,, Ruby	136	12 9 3 10	8 7 0	914 3 6	9¼ 1/16	105·4
Gwinear Consols	249	10 16 1 9	..	637 4 0	4¼	121·5
Huel Jane	219	10 12 3 2	2 17 6	653 6 0	4⅞	117·7
South Huel Fortune	82	10 5 0 15	..	715 14 0	12½	92·
Great Work	46	6 13 1 16	..	427 16 0	14⅜ 1/16	83·7
Huel Tryphena	27	6 10 3 22	..	496 2 6	24¼	86·19
East Relistian	93	6 10 1 22	5 14 0	454 6 6	7	108·10
Sundry Small Mines	1,420	96 16 3 3	5 8 6	6,432 11 6	6¾ 1/16	106·14
	155,985	12,754 0 3 22	..	889,287 0 6	8¼	103·7

For the average Price per Ton of Ore, we are indebted to Gryll's Annual Mining Sheets, which are made up to Midsummer; the other portions of the Table are completed to Christmas, from the ticketing papers and other sources.

1846	1847	Total Quantity Sold from each Mine in 21 Cwts.	MINES.
Tons.	Tons.	Tons.	
• •	• •	23	Sundries.
• •	• •	428	Snowdon.
• •	• •	6,291	Drws-y-Coed.
• •	• •	12	Bwlch-Mulchan.
59	43	383	Aberdovey.
630	235	10,942	Llandidno.
• •	• •	5,231	Anglesea.
[illegible]	[illegible]	371	Caernarvon

Total Quantity Sold Annually.		
Years.	Welsh Mines.	Irish Mines.
	Tons.	Tons.
1804	52	• •
1805	• •	• •
1806	41	62
1807	68	810

TABLES SHOWING THE SALES OF COPPER ORE AT SWANSEA, FROM THE COMMENCEMENT OF THE PUBLICATION OF THESE SALES IN 1804 TO 1847.

Compiled from the published Documents, by Robert Hunt, Keeper of Mining Records.

No. 1.—SALES AT SWANSEA FROM WELSH MINES.

Mines.	1804	1805	1806	1807	1808	1809	1810	1811	1812	1813	1814	1815	1816	1817	1818	1819	1820	1821	1822	1823	1824	1825	1826	1827	1828	1829	1830	1831	1832	1833	1834	1835	1836	1837	1838	1839	1840	1841	1842	1843	1844	1845	1846	1847	Total Quantity sold from each Mine in 21 Cwts.	Mines.
	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	
Sundries	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	5	..	4	12	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	2	..	..	23	Sundries.
Snowdon	12	..	29	40	33	38	26	20	..	..	..	..	..	..	..	13	70	35	20	..	..	14	..	..	..	24	22	..	..	..	..	..	..	..	..	..	..	..	32	..	..	..	..	..	428	Snowdon.
Drws-y-Coed	40	..	..	..	..	..	..	..	..	28	..	..	..	..	..	..	..	75	103	112	53	82	73	27	55	118	417	629	916	561	762	548	333	295	373	434	123	..	..	..	..	104	..	..	6,291	Drws-y Coed.
Bwlch-Mulchan	..	..	12	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	12	Bwlch-Mulchan.
Aberdovey	..	..	..	28	..	..	..	..	..	..	..	..	..	..	..	21	20	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	22	47	94	49	59	43	383	Aberdovey.
Llandidno	..	..	..	..	279	202	374	..	..	414	321	920	503	330	193	35	34	28	84	88	44	169	51	158	118	91	42	94	49	45	..	..	53	755	800	697	633	292	184	853	489	625	630	235	10,942	Llandidno.
Anglesea	..	..	..	..	..	..	..	68	622	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	1,300	2,386	387	..	..	125	..	..	..	..	..	343	..	..	5,231	Anglesea.
Caernarvon	..	..	..	..	..	..	..	..	..	..	..	159	..	31	..	..	..	..	43	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	38	..	..	271	Caernarvon.
Ross Brin	..	..	..	..	..	..	..	..	..	..	..	..	37	36	27	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	100	Ross Brin.
Llanberris	..	..	..	..	..	..	..	..	..	..	..	..	60	..	..	..	..	..	77	29	91	160	91	205	165	292	469	369	1,169	701	859	479	585	770	288	215	147	..	..	..	..	..	..	..	7,221	Llanberris.
Turf Ore	..	..	..	..	..	..	..	..	..	..	..	..	..	25	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	25	Turf Ore.
Penrhyn ddu	..	..	..	..	..	..	..	..	..	..	..	..	..	..	5	..	..	..	..	..	..	16	..	..	2	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	23	Penrhyn ddu.
Llansaintfraid	..	..	..	..	..	..	..	..	..	..	..	..	..	..	7	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	7	Llansaintfraid.
Dolgelly	..	..	..	..	..	..	..	..	..	..	..	..	..	..	15	..	..	..	..	..	..	..	..	21	..	..	..	..	..	..	..	..	..	..	104	209	59	..	..	..	..	..	..	..	408	Dolgelly.
Barmouth	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	21	..	..	..	15	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	36	Barmouth.
Llywidd	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	53	81	100	65	49	52	35	67	126	63	37	..	..	32	..	52	..	93	160	228	133	303	173	..	..	..	..	1,902	Llywidd.
Clogwin Coch	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	4	..	..	..	..	..	..	111	32	..	..	..	..	..	..	..	24	6	..	..	..	..	..	..	..	..	177	Clogwin Coch.
Llandidno New Mine	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	187	37	71	135	294	501	251	183	..	..	132	..	..	..	..	315	..	..	..	..	..	..	..	..	..	2,106	Llandidno New Mine.
Mynydd-y-Gareg	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	13	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	13	Mynydd-y-Gareg.
Bron-y-gader	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	20	18	4	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	42	Bron-y-gader.
Dolfrwynog	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	50	421	520	290	170	94	..	..	..	..	..	..	100	18	10	..	..	..	..	..	42	..	..	27	1,742	Dolfrwynog.
Mona	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	76	..	..	2,097	1,625	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	6,798	Mona.
Towyn	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	9	14	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	23	Towyn.
Sygun	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	92	129	62	71	75	47	..	..	..	..	..	..	52	194	62	..	91	34	..	..	..	..	..	909	Sygun.
Havod-y-Llan	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	23	33	..	..	..	..	..	..	..	..	..	..	..	..	..	10	..	34	..	..	..	81	..	181	Havod-y-Llan.
Sunnea Dylluam	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	17	..	217	154	412	259	1,032	347	301	227	152	134	305	317	136	..	..	..	..	..	..	..	4,010	Sunnea Dylluam.
Pantywrach	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	20	6	8	6	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	40	Pantywrach.
Merioneth	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	24	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	24	Merioneth.
Creflwyn	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	35	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	35	Creflwyn.
Havod-y-Porth	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	20	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	20	Havod-y-Porth.
Gilvach	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	10	30	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	40	Gilvach.
Llyndy	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	9	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	9	Llyndy.
Ffestiniog	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	8	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	8	Ffestiniog.
Rhosmanach	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	39	95	54	18	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	206	Rhosmanach.
Amlwch Precip	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	82	..	..	..	..	..	..	..	..	..	..	..	..	..	82	Amlwch Precip.
Llandegai	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	36	36	43	53	14	..	..	..	..	..	..	..	..	182	Llandegai.
Ty-gwyn	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	65	..	..	109	..	..	..	..	..	..	..	..	..	174	Ty-gwyn.
Brynvillin	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	29	..	102	11	..	..	..	..	..	..	..	..	..	142	Brynvillin.
North Wales	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	12	..	..	..	..	..	..	..	..	..	..	12	North Wales.
Cwm	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	23	55	..	..	..	..	..	..	..	..	..	78	Cwm.
Cambrian	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	12	29	..	9	..	..	..	..	..	..	..	50	Cambrian.
Margam	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	514	10	..	..	..	..	..	..	..	..	524	Margam.
Pen-yr-alt	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	107	52	..	..	..	..	..	..	..	..	159	Pen-yr-alt.
Aberglaslyn	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	26	30	..	..	..	..	..	..	..	..	56	Aberglaslyn.
Parys Mine	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	280	..	..	..	..	..	113	..	..	393	Parys Mine.
Bronsgellog	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	8	..	..	..	..	..	..	..	..	8	Bronsgellog.
Llanidloes	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	18	9	..	28	30	21	13	20	12	151	Llanidloes.
Llyndu	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	171	294	220	..	41	..	..	..	726	Llyndu.
Melin Cythan	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	370	..	..	..	..	..	..	370	Melin Cythan.
Cwm Sebon	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	13	26	35	12	86	Cwm Sebon.
Vigra and Clogau	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	601	210	..	811	Vigra and Clogan.
Tyn-y-Wern	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	11	11	Tyn-y-Wern.

No. 2.—SALES AT SWANSEA FROM IRISH MINES.

Sundries	..	..	..	..	..	..	10	..	..	..	..	3	..	..	..	..	..	..	..	..	..	..	4	5	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	22	Sundries.
Lackamore	..	..	40	76	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	17	..	..	..	..	..	..	..	..	19	143	407	510	648	411	260	166	119	124	69	3,009	Lackamore.
Ross Island	..	..	22	674	826	530	578	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	211	752	560	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	4,153	Ross Island.
Longhshinney	..	..	..	60	31	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	18	..	..	..	109	Loughshinney.
Cronebane	..	..	..	..	534	..	..	..	..	..	..	..	..	..	..	..	..	..	..	302	1,155	1,544	1,335	1,514	1,280	1,079	1,700	2,473	2,265	1,266	2,181	2,880	3,112	2,255	1,180	1,253	1,671	228	405	759	819	1,635	2,235	1,241	38,301	Cronebane.
Tipperary	..	..	..	..	..	..	15	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	19	..	..	..	..	..	..	..	..	..	34	Tipperary.
Malagow	..	..	..	..	..	..	..	68	75	38	81	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	262	Malagow.
Crow Island	..	..	..	..	..	..	..	..	45	41	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	86	Crow Island.
Allihies	..	..	..	..	..	..	..	..	..	134	300	631	673	..	148	1,218	1,862	1,945	1,501	2,577	2,350	2,966	1,809	2,613	2,693	2,040	2,723	3,177	5,267	5,787	6,819	7,288	5,993	4,835	4,964	5,460	4,808	4,777	1,278	..	..	..	..	..	88,636	Allihies.
Ballycumich	..	..	..	..	..	..	..	..	..	..	16	42	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	58	Ballycumich.
Horse Island	..	..	..	..	..	..	..	..	..	..	5	..	..	..	..	..	20	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	25	Horse Island.
Burnt Irish	..	..	..	..	..	..	..	..	..	..	27	24	..	..	95	167	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	313	Burnt Irish.
Galway	..	..	..	..	..	..	..	..	..	..	..	..	..	9	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	9	Galway.
Ballydanab	..	..	..	..	..	..	..	..	..	..	..	..	..	..	106	146	288	38	20	..	..	..	8	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	606	Ballydahab.
Cappagh	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	30	57	33	..	..	..	60	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	180	Cappagh.
Wicklow	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	352	400	..	..	..	937	1,889	571	342	99	119	..	..	..	..	..	8	..	..	..	..	..	..	..	..	..	4,717	Wicklow.
Ballymurtagh	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	17	302	513	525	486	520	..	..	..	..	388	1,582	3,389	5,500	4,437	7,085	5,280	6,562	3,269	..	377	1,385	3,641	3,063	2,718	872	52,111	Ballymurtagh.
Nanmor	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	23	35	5	6	5	..	7	..	..	..	..	..	..	..	..	..	..	..	..	..	..	12	..	..	..	93	Nanmor.
Conham	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	42	216	19	20	109	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	406	Conham.
Tigrony	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	27	202	251	526	1,024	1,279	1,633	1,606	1,617	1,339	1,002	1,334	1,666	1,529	1,800	1,662	1,718	1,346	273	279	401	353	657	644	422	24,590	Tigrony.
Landore	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	40	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	40	Landore.
Knockmahon	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	17	58	170	613	2,255	2,189	1,928	998	994	2,204	3,316	5,068	7,034	7,372	7,875	7,713	8,153	9,111	8,362	7,214	5,721	4,958	93,323	Knockmahon.
Audley	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	387	203	359	367	152	11	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	1,479	Audley.
Knockmalaur	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	111	123	14	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	248	Knockmalaur.
Kilduanne	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	59	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	75	..	81	215	Kilduanne.
Ballygahan	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	57	59	108	..	..	48	363	428	310	219	1,210	503	198	..	105	28	34	42	56	33	3,801	Ballygahan.
Connorree	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	82	610	2,200	2,076	2,129	967	639	338	150	82	256	641	624	586	..	..	11,380	Connorree.
West Cork	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	81	187	58	..	..	..	..	..	..	..	..	..	..	326	West Cork.
Bawneshall	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	22	..	25	..	..	..	..	..	..	..	47	Bawneshall.
Fingal	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	40	27	..	..	..	..	..	..	67	Fingal.
Cosheen	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	197	264	308	360	608	125	46	49	1,957	Cosheen.
Kenmare Ardtully	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	77	274	68	31	66	120	144	..	780	Kenmare Ardtully.
Skull	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	35	..	84	..	..	..	..	119	Skull.
Bearhaven	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	3,613	4,446	4,924	5,835	5,758	5,807	30,383	Bearhaven.
Belfast	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	33	44	..	..	..	77	Belfast.
Dreenatra	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	61	..	..	..	..	61	Dreenatra.
Dhurode	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	97	102	30	..	229	Dhurode.
Roaring Water	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	14	..	..	..	14	Roaring Water.
Dublin Slag	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	60	66	..	..	126	Dublin Slag.
Shionagree	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	21	..	..	..	21	Shionagree.
Holyford	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	8	77	841	926	Holyford.

Total Quantity Sold Annually.

Years.	Welsh Mines.	Irish Mines.
	Tons.	Tons.
1804	52	..
1805	..	..
1806	41	62
1807	68	810
1808	312	1,391
1809	240	530
1810	400	603
1811	88	68
1812	622	120
1813	442	213
1814	321	429
1815	1,079	700
1816	600	673
1817	422	9
1818	217	349
1819	90	1,531
1820	124	2,200
1821	191	2,040
1822	412	1,923
1823	564	3,673
1824	358	4,471
1825	1,191	5,350
1826	1,115	4,271
1827	1,140	7,383
1828	3,555	8,510
1829	6,076	7,041
1830	1,788	9,115
1831	1,442	9,707
1832	3,184	11,399
1833	1,786	11,293
1834	3,336	17,280
1835	3,770	22,123
1836	1,698	21,013
1837	2,216	22,306
1838	3,410	22,161
1839	2,637	23,613
1840	1,525	20,166
1841	1,180	14,321
1842	857	15,253
1843	1,133	17,600
1844	700	20,063
1845	1,914	19,647
1846	1,035	17,553
1847	340	14,373
Total.	53,701	363,339

832	1833	1834	1847	Total Quantity Sold from each Mine in 21 Cwts.	MINES.	The Total Quantity of Ore Sold Annually from these Mines. Years.	Tons.
Tons.	Tons.	Tons.	Tons.	Tons.			
..	..	..	..	35	Sundries.		
..	..	..	..	66	Lancashire.	1815	77
..	..	..	..	76	Copper Ashes.		
..	..	..	..	2,800	Ecton.	1816	35
..	..	..	..	215	Buckingham.		
..	..	..	..	31	Swanterstown.	1817	..
..	..	..	..	769	Mixen.		
..	..	..	..	147	Burgoyne.	1818	317
..	..	..	..	90	Carberry.		
..	..	..	..	178	Mineral Field.	1819	1,796
..	..	..	..	565	Clayton.		
..	..	..	..	182	Cally.	1820	1,408
..	..	..	..	156	Buckfastleigh.		
..	..	..	..	16	Cornish.	1821	957
..	..	..	..	240	Crewshole.		
..	..	..	..	78	Westmoreland.	1822	521
..	..	..	..	46	Arkindale.		
..	..	..	..	258	Bristol.	1823	633
..	..	4	..	23	Caldbeck.		
40	24	83	..	856	Stowcragg.	1824	436
..	..	..	..	93	Bottle Hill.		
..	..	..	..	81	Scar Ends.	1825	2,061
..	..	..	..	465	Forest.		
..	..	..	..	1,603	Fowey Consols.	1826	505
..	74	..	..	812	Phœnix Metal.		
24	..	..	..	1,014	Conistone.	1827	508
..	..	..	..	196	Molland.		
..	..	..	..	44	Tebay.	1828	320
..	..	..	..	33	Isle of Man.		
41	14	7	..	576	Leehousewell.	1829	720
..	..	..	..	46	Seawood.		
41	249	268	60	3,643	Laxey.	1830	415
..	..	..	..	225	Huel Hope.		
..	..	..	..	715	Huel Union.	1831	540
..	..	..	..	77	Beeralston.		
..	..	15	..	210	Mill Slag.	1832	646
..	..	..	..	75	Dandycombe.		
..	..	..	..	426	Holmbush.	1833	361
..	..	..	..	77	Denyscombe.		
..	..	..	..	429	Hulm Slag.	1834	377
..	..	..	..	1,419	Crown.		
..	..	..	..	19	Heston.	1835	268
..	..	..	..	11	Lisburne.		
..	..	..	..	7	Trevorgus.	1836	535
..	..	..	..	50	Eardistone.		
			..	510	James' Ore.	1837	179

No. 3.—SALES AT SWANSEA, FROM ENGLISH MINES.

MINES.	1815	1816	1817	1818	1819	1820	1821	1822	1823	1824	1825	1826	1827	1828	1829	1830	1831	1832	1833	1834	1835	1836	1837	1838	1839	1840	1841	1842	1843	1844	1845	1846	1847	Total Quantity Sold from each Mine in 21 Cwts.	MINES.
	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	
Sundries	..	6	..	..	..	..	..	..	..	..	..	..	2	8	..	..	2	..	..	..	..	..	..	6	..	..	4	..	..	7	..	..	..	35	Sundries.
Lancashire	37	29	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	66	Lancashire.
Copper Ashes	40	..	..	36	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	76	Copper Ashes.
Ecton	..	..	..	221	864	683	712	320	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	2,800	Ecton.
Buckingham	..	..	..	29	13	22	141	..	10	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	215	Buckingham.
Swanterstown	..	..	..	31	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	31	Swanterstown.
Mixen	..	..	..	..	546	223	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	769	Mixen.
Burgoyne	..	..	..	..	147	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	147	Burgoyne.
Carberry	..	..	..	..	48	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	42	..	..	..	..	..	..	..	..	..	90	Carberry.
Mineral Field	..	..	..	..	178	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	178	Mineral Field.
Clayton	..	..	..	..	..	480	48	37	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	565	Clayton.
Cally	..	..	..	..	..	..	56	118	..	..	8	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	182	Cally.
Buckfastleigh	..	..	..	..	..	..	..	30	..	..	..	126	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	156	Buckfastleigh.
Cornish	..	..	..	..	..	..	..	16	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	16	Cornish.
Crewshole	..	..	..	..	..	..	..	..	188	23	4	..	..	..	25	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	240	Crewshole.
Westmoreland	..	..	..	..	..	..	..	..	34	44	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	78	Westmoreland.
Arkindale	..	..	..	..	..	..	..	..	17	..	13	8	8	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	46	Arkindale.
Bristol	..	..	..	..	..	..	..	..	239	..	..	2	..	12	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	5	..	..	..	258	Bristol.
Caldbeck	..	..	..	..	..	..	..	..	4	..	..	4	..	6	3	..	2	..	..	4	..	..	..	..	..	..	..	..	..	..	..	..	..	23	Caldbeck.
Stowceragg	..	..	..	..	..	..	..	..	48	110	129	65	52	30	35	30	9	40	24	83	116	45	..	..	..	..	..	..	..	..	40	..	..	856	Stowceragg.
Bottle Hill	..	..	..	..	..	..	..	..	93	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	93	Bottle Hill.
Scar Ends	..	..	..	..	..	..	..	..	..	2	36	43	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	81	Scar Ends.
Forest	..	..	..	..	..	..	..	..	..	257	208	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	465	Forest.
Fowey Consols	..	..	..	..	..	..	..	..	..	..	1,603	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	1,603	Fowey Consols.
Phœnix Metal	..	..	..	..	..	..	..	..	..	..	4	9	27	13	21	..	..	..	74	..	..	..	..	..	..	..	133	469	62	..	..	..	..	812	Phœnix Metal.
Conistone	..	..	..	..	..	..	..	..	..	..	56	133	227	124	189	..	61	224	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	1,014	Conistone.
Molland	..	..	..	..	..	..	..	..	..	..	..	38	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	7	14	134	3	..	196	Molland.
Tebay	..	..	..	..	..	..	..	..	..	..	..	44	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	44	Tebay.
Isle of Man	..	..	..	..	..	..	..	..	..	..	..	33	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	33	Isle of Man.
Leehousewell	..	..	..	..	..	..	..	..	..	..	..	..	179	99	35	95	106	41	14	7	..	..	..	..	..	..	..	..	..	..	..	..	..	576	Leehousewell.
Seawood	..	..	..	..	..	..	..	..	..	..	..	..	13	..	33	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	46	Seawood.
Laxey	..	..	..	..	..	..	..	..	..	..	..	..	..	28	161	238	283	341	249	268	77	89	69	121	183	278	368	406	207	46	79	92	60	3,643	Laxey.
Huel Hope	..	..	..	..	..	..	..	..	..	..	..	..	..	..	173	52	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	225	Huel Hope.
Huel Union	..	..	..	..	..	..	..	..	..	..	..	..	..	..	45	..	..	..	..	..	..	..	..	670	..	..	..	..	..	..	..	..	..	715	Huel Union.
Beeralston	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	77	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	77	Beeralston.
Mill Slag	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	15	..	..	..	..	..	..	..	195	..	..	..	..	..	210	Mill Slag.
Dandycombe	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	75	..	..	..	..	..	..	..	..	..	..	..	..	75	Dandycombe.
Holmbush	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	324	102	..	..	..	..	..	..	..	..	..	..	426	Holmbush.
Denyscombe	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	77	..	..	..	..	..	..	..	..	..	..	..	77	Denyscombe.
Hulm Slag	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	8	125	173	89	..	34	..	..	..	..	..	429	Hulm Slag.
Crown	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	1,419	..	..	..	..	..	..	..	..	1,419	Crown.
Heston	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	19	..	..	..	..	..	..	..	..	19	Heston.
Lisburne	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	11	..	..	..	..	..	..	..	..	11	Lisburne.
Trevorgus	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	7	..	..	..	..	..	..	..	..	7	Trevorgus.
Eardistone	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	50	..	..	..	..	..	..	..	50	Eardistone.
James' Ore	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	335	175	..	..	..	..	..	..	510	James' Ore.
Gloucestershire	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	8	33	29	6	17	35	30	158	Gloucestershire.
South Molton	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	17	..	5	..	..	2	..	24	South Molton.
Brass Slag	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	77	..	..	..	..	..	77	Brass Slag.
Ivy Slag	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	00	66	..	..	12	..	178	Ivy Slag.
Vine Slag	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	165	77	121	51	35	85	434	Vine Slag.
Prince	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	64	20	..	..	..	..	384	Prince
Vipond Slag	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	311	..	..	..	..	..	11	Vipond Slag.
Regulus	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	98	256	..	..	..	..	354	Regulus.
Ulpha	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	48	..	..	..	..	..	48	Ulpha.
Eagle	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	10	..	..	..	..	..	10	Eagle.
North Molton	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	14	15	4	5	..	38	North Molton.
Huel Buller	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	13	..	..	..	..	13	Huel Buller.
Davies's Ore	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	35	168	..	..	203	Davies's Ore.
Falcon	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	12	..	..	..	12	Falcon.
Huel Bandon	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	19	..	..	..	19	Huel Bandon.
Holden's Slag	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	51	..	65	62	178	Holden's Slag.
Hayle	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	45	..	..	..	45	Hayle.
Devonport Slag	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	23	7	..	..	30	Devonport Slag.
London Slag	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	19	10	13	..	42	London Slag.
Stephens' Slag	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	12	..	..	..	12	Stephens' Slag.
Rose Slag	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	42	..	..	42	Rose Slag.
Glasgow Slag	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	49	36	169	254	Glasgow Slag.
Harris's Ore	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	21	..	..	21	Harris's Ore.
Abbey Regulus	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	59	..	59	Abbey Regulus.
Forest Slag	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	69	..	69	Forest Slag.
Yeo Slag	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	53	..	53	Yeo Slag.
Sampson's Ore	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	50	..	50	Simpson's Slag.
Brown's Slag	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	20	..	20	Brown's Slag.

The Total Quantity of Ore Sold Annually from these Mines.

Years.	Tons.
1815	77
1816	35
1817	..
1818	317
1819	1,796
1820	1,408
1821	957
1822	521
1823	633
1824	436
1825	2,061
1826	505
1827	508
1828	320
1829	720
1830	415
1831	540
1832	646
1833	361
1834	377
1835	268
1836	535
1837	179
1838	964
1839	1,812
1840	752
1841	705
1842	1,910
1843	756
1844	430
1845	622
1846	549
1847	406
Total .	22,521

Total Quantity Sold from each Mine in 21 Cwts.	MINES.
Tons.	
29	Sundries.
8,357	Norway.
82,580	Chili.
349	United States.
57	Bolivar.
62	Boulard.
1,798	Cobija.
36,033	Cuba.
14,887	Copiapo.
9,306	Valparaiso.
172,634	Cobre.
351	Arietta Pertinencias.
171	Mexican.
55	Foreign Slag.
236	Coquimbo.
42	Peru.
57,230	Santiago.
47	Florence.
201	Virgia Gorda.
297	Havana.
92	Palatine.
1,112	Bacuranao.
28	New York.
377	Chaneral.
515	Mount San Fernando.
17	Maxthallan.
20	Preceosa.
47	Messina.
8,246	San Jose in Cobre.
822	Australian.
62	Spanish.
52	German.
46	Capricorn.
31	Pinal.
1,454	Pennsylvania.
557	Montacute.
556	Kaw-aw.
2,354	Kapunda.
1,547	Victoria.
28	Mediterranean.
306	Kanmantoo.
119	Paringa.
10	Nuevitas.
181	Sydney.
144	French Slag.
5,389	Burra Burra.
499	Recompensa.
93	Princess Royal.
52	Candelaria.
334	New Zealand.
57	San Andreas.

The Total Quantity of Ore Sold Annually from these Mines.	
Years.	Tons.
1828	199
1829	668
1830	934
1831	975
1832	641
1833	1,059
1834	2,077
1835	6,758
1836	9,046
1837	14,521
1838	19,868
1839	24,092
1840	35,354
1841	41,364
1842	44,392
1843	40,739
1844	45,491
1845	46,643
1846	39,348
1847	35,700
Total .	409,869

The Total Quantity of British and Foreign Ore sold Annually at Swansea, from 1804 to 1847 inclusive.	
Years.	Tons.
1804	52
1805	•
1806	103
1807	878
1808	1,703
1809	770
1810	1,003
1811	156
1812	742
1813	655
1814	750
1815	1,856
1816	1,308
1817	431
1818	913
1819	3,417
1820	3,732
1821	3,188
1822	2,856
1823	4,870
1824	5,265
1825	8,602
1826	5,891
1827	9,031
1828	12,584
1829	14,508
1830	12,252
1831	12,664
1832	15,870
1833	14,499
1834	23,070
1835	32,919
1836	32,292
1837	39,222
1838	46,403
1839	52,154
1840	57,797
1841	57,570
1842	62,412
1843	60,228
1844	66,684
1845	68,826
1846	58,485
1847	50,819
Total .	849,430

No. 4.—SALES AT SWANSEA, FROM FOREIGN MINES.

MINES.	1828	1829	1830	1831	1832	1833	1834	1835	1836	1837	1838	1839	1840	1841	1842	1843	1844	1845	1846	1847	Total Quantity Sold from each Mine in 21 Cwts.	MINES.
	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	
Sundries . . .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	3	. .	. .	. .	6	10	3	7	29	Sundries.
Norway	199	456	733	674	531	624	453	329	1,450	1,277	1,023	479	55	38	36	. .	. .	. .	. .	. .	8,357	Norway.
Chili	. .	187	201	244	33	435	1,107	2,087	3,849	5,481	6,064	6,267	7,318	9,672	7,057	8,356	9,846	3,806	6,701	3,869	82,580	Chili.
United States . .	. .	25	. .	. .	15	. .	. .	. .	20	14	. .	. .	140	. .	69	39	10	17	. .	. .	349	United States.
Bolivar	. .	. .	. .	57	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	57	Bolivar.
Boulard	. .	. .	. .	. .	62	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	62	Boulard.
Cobija	. .	. .	. .	. .	. .	. .	517	661	379	. .	. .	164	. .	. .	. .	. .	. .	77	. .	. .	1,798	Cobija.
Cuba	. .	. .	. .	. .	. .	. .	. .	3,426	299	1,059	967	3,133	1,346	732	445	2,136	4,309	5,591	6,390	6,200	36,033	Cuba.
Copiapo	. .	. .	. .	. .	. .	. .	. .	222	498	772	1,935	935	1,511	626	2,278	1,259	1,239	666	1,020	1,926	14,887	Copiapo.
Valparaiso . . .	. .	. .	. .	. .	. .	. .	. .	33	55	572	2,689	1,234	1.496	97	140	1,935	772	283	. .	. .	9,306	Valparaiso.
Cobre.	. .	. .	. .	. .	. .	. .	. .	. .	2,077	5,346	6,758	10,732	16,699	22,094	22,544	16,433	17,744	22,741	14,755	14,711	172,634	Cobre.
Arietta Pertinencias	. .	. .	. .	. .	. .	. .	. .	. .	351	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	351	Arietta Pertinencias.
Mexican	. .	. .	. .	. .	. .	. .	. .	. .	13	. .	156	. .	. .	. .	. .	2	. .	. .	. .	. .	171	Mexican.
Foreign Slag. . .	. .	. .	. .	. .	. .	. .	. .	. .	55	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	55	Foreign Slag.
Coquimbo .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	236	. .	. .	. .	. .	. .	. .	. .	. .	. .	236	Coquimbo.
Peru	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	40	. .	. .	2	. .	. .	. .	. .	. .	. .	42	Peru.
Santiago	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	1,119	6,786	7,910	11,573	9,224	6,873	7,930	4,808	1,007	57,230	Santiago.
Florence	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	29	. .	18	. .	. .	. .	. .	. .	. .	47	Florence.
Virgia Gorda . .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	47	154	. .	. .	. .	. .	. .	201	Virgia Gorda.
Havana	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	128	. .	. .	. .	. .	169	. .	297	Havana.
Palatine	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	92	. .	. .	. .	. .	. .	92	Palatine.
Bacuranao . . .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	4	659	. .	449	. .	. .	1,112	Bacuranao.
New York . . .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	22	. .	6	. .	. .	28	New York.
Chaneral. . . .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	377	. .	. .	. .	. .	377	Chaneral.
Mount San Fernando	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	278	237	. .	. .	. .	515	Mount San Fernando.
Maxthallan . . .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	17	. .	. .	. .	. .	17	Maxthallan.
Preceosa	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	2	18	. .	. .	. .	20	Preceosa.
Messina	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	37	. .	9	1	47	Messina.
San Jose in Cobre .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	4,168	2,931	1,147	. .	8,246	San Jose in Cobre.
Australian . . .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	61	503	258	. .	822	Australian.
Spanish	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	42	. .	20	. .	62	Spanish.
German	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	52	. .	. .	. .	52	German.
Capricorn . . .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	46	. .	. .	. .	46	Capricorn.
Pinal	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	31	. .	. .	. .	31	Pinal.
Pennsylvania . .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	372	675	407	1,454	Pennsylvania.
Montacute . . .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	237	265	55	557	Montacute.
Kaw-aw	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	129	249	178	556	Kaw-aw.
Kapunda	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	43	831	1,480	2,354	Kapunda.
Victoria	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	852	695	. .	1,547	Victoria.
Mediterranean . .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	28	. .	28	Mediterranean.
Kanmantoo . . .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	78	228	306	Kanmantoo.
Paringa	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	19	100	119	Paringa.
Nnevitas	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	10	. .	10	Nuevitas.
Sydney	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	67	114	181	Sydney.
French Slag . . .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	113	31	144	French Slag.
Burra Burra. . .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	1,038	4,351	5,389	Burra Burra.
Recompensa . . .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	499	499	Recompensa.
Princess Royal . .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	93	93	Princess Royal.
Candelaria . . .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	52	52	Candelaria.
New Zealand . .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	334	334	New Zealand.
San Andreas. . .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	57	57	San Andreas.

The Total Quantity of Ore Sold Annually from these Mines.	
Years.	Tons.
1828	199
1829	668
1830	934
1831	975
1832	641
1833	1,059
1834	2,077
1835	6,758
1836	9,046
1837	14,521
1838	19,868
1839	24,092
1840	35,354
1841	41,364
1842	44,392
1843	40,739
1844	45,491
1845	46,643
1846	39,348
1847	35,700
Total .	409,869

The Total Quantity of British and Foreign Ore sold Annually at Swansea, from 1804 to 1847 inclusive.	
Years.	Tons.
1804	52
1805	.
1806	103
1807	878
1808	1,703
1809	770
1810	1,003
1811	156
1812	742
1813	655
1814	750
1815	1,856
1816	1,308
1817	431
1818	913
1819	3,417
1820	3,732
1821	3,188
1822	2,856
1823	4,870
1824	5,265
1825	8,602
1826	5,891
1827	9,031
1828	12,584
1829	14,508
1830	12,252
1831	12,664
1832	15,870
1833	14,499
1834	23,070
1835	32,919
1836	32,292
1837	39,222
1838	46,403
1839	52,154
1840	57,797
1841	57,570
1842	62,412
1843	60,228
1844	66,684
1845	68,826
1846	58,485
1847	50,819
Total .	849,430

INDEX

TO THE SECOND VOLUME.

Part II.

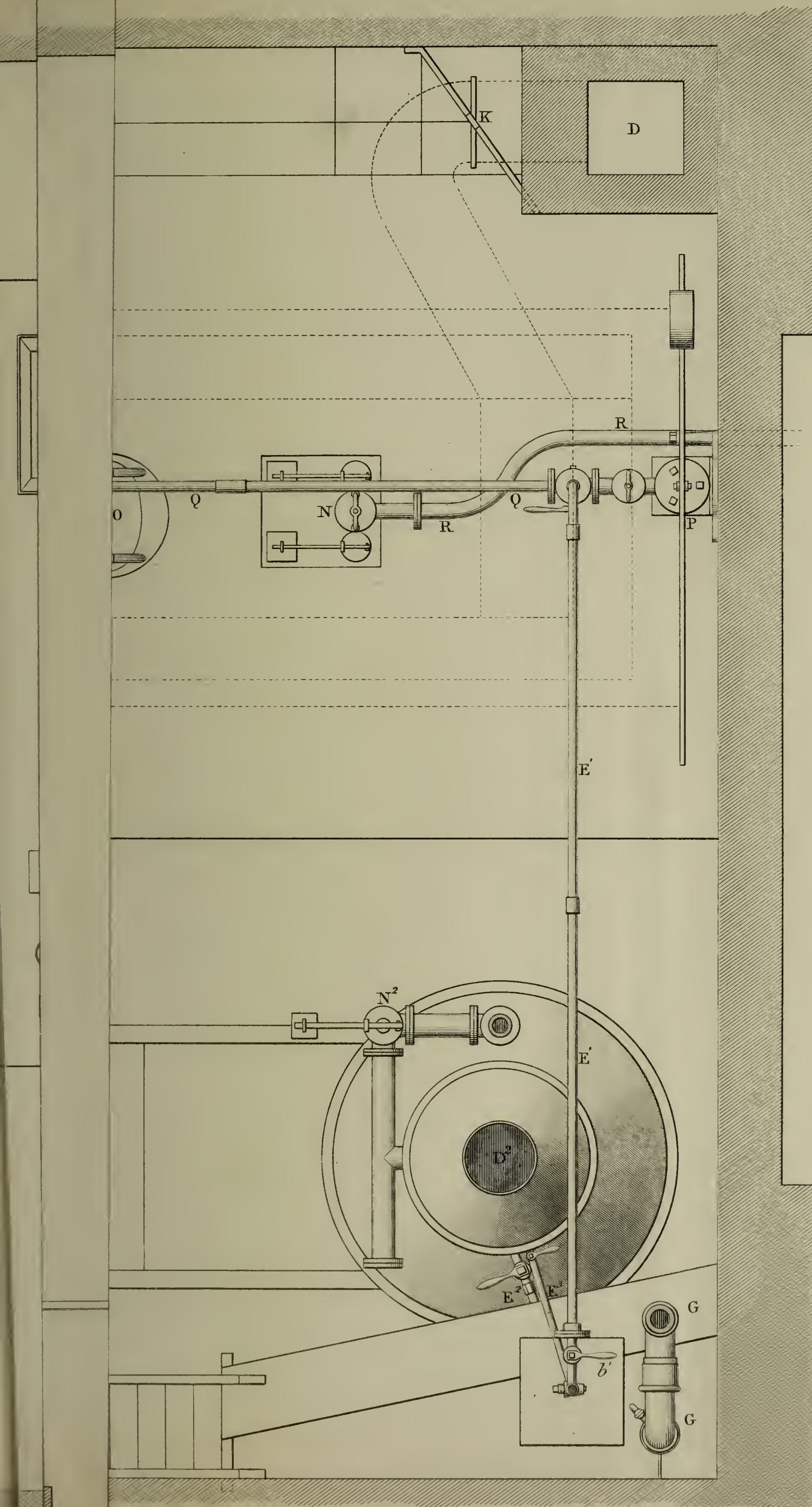
ERRATA.

In the paper on the Structure and Affinities of *Lepidostrobi*, at p. 144 (line 11 from the bottom), *for* " at their bases," *read* " on their surface ;" and *vice versâ*.

And at line 2 from the bottom of the same page, *for* " bores," *read* " bore."

In the account of the British Fossil *Asteriadæ*, Professor Sedgwick's fossil *Urasteriæ* are stated, by mistake, as from the " Lower " *instead of* " Upper Silurian Rocks of Westmoreland ;" *see* pp. 460, 463, and 464. Also in the Table, at p. 481.

LONDON:
Printed by WILLIAM CLOWES and SONS, Stamford Street,
For Her Majesty's Stationery Office.



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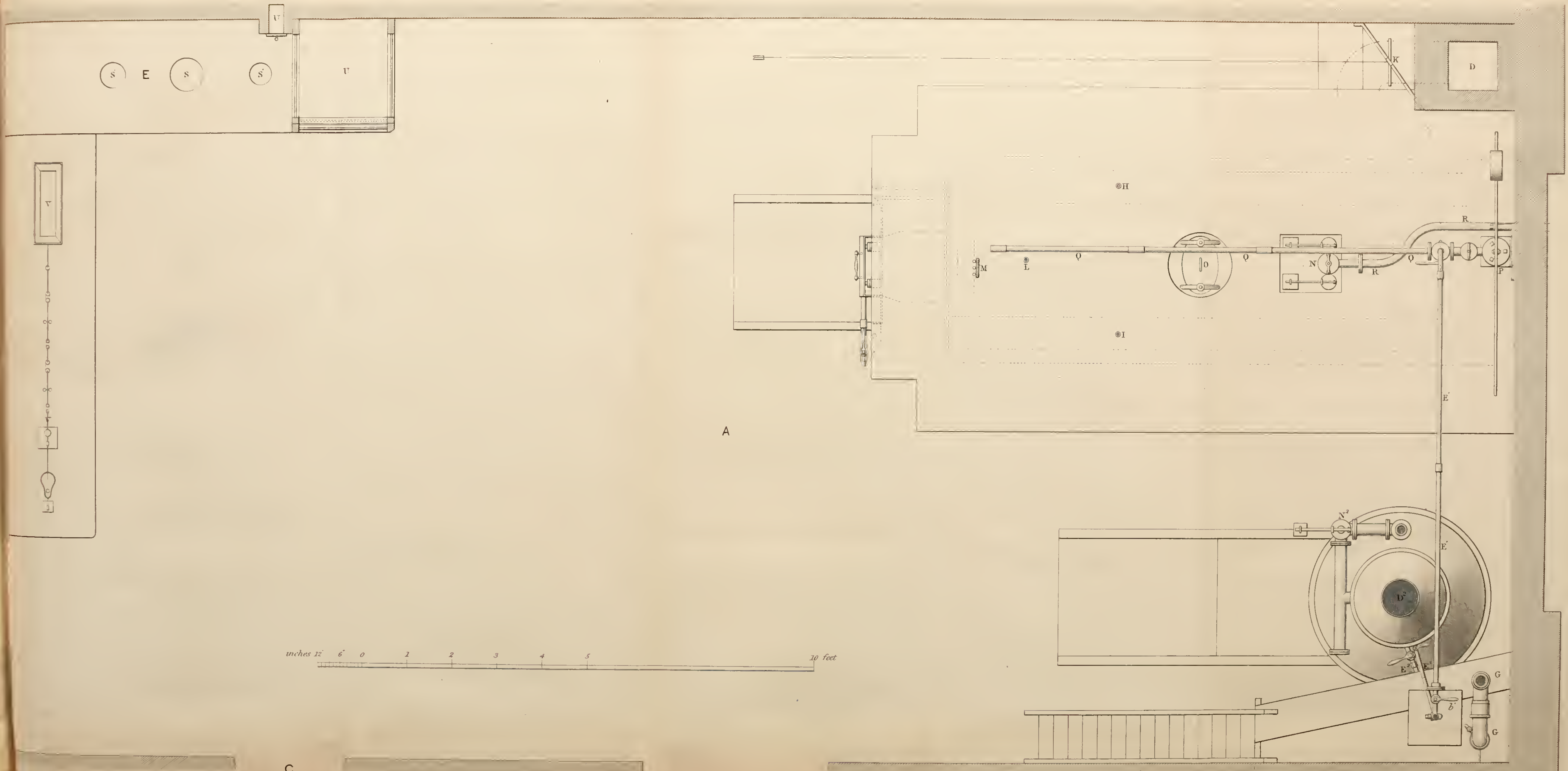
J. W. Lowry, sculp.t



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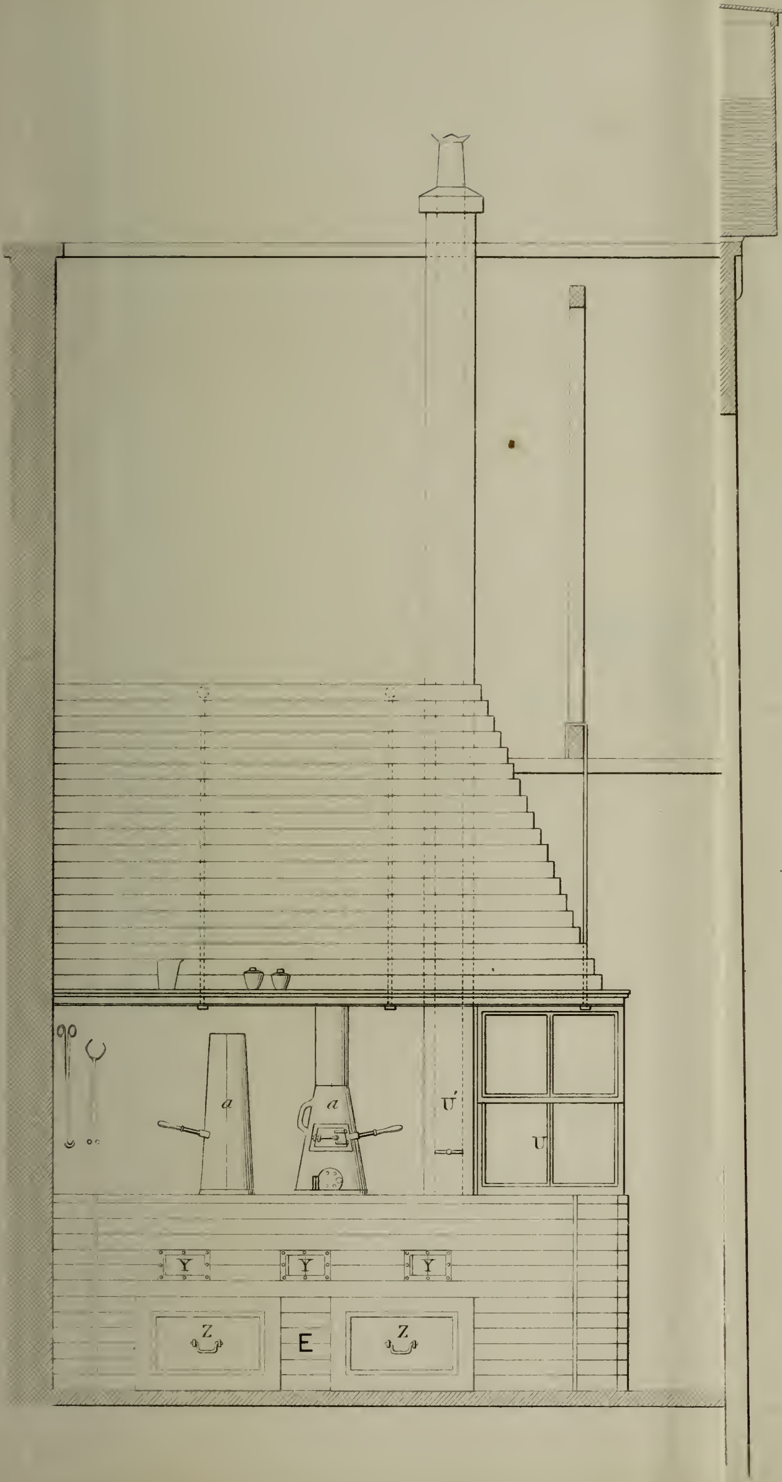
J W Lowry sculp t



P. Stopford, delin.t

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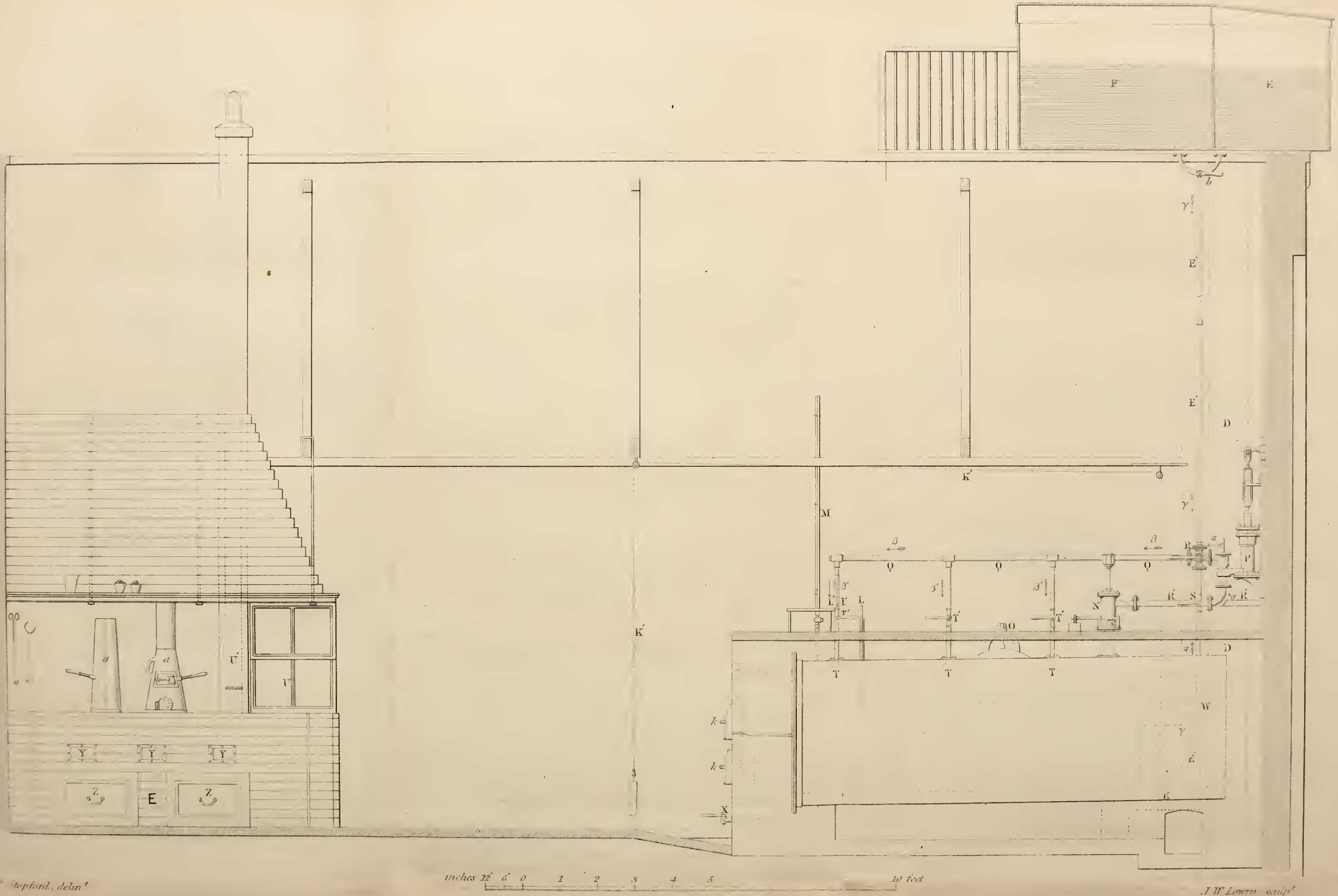
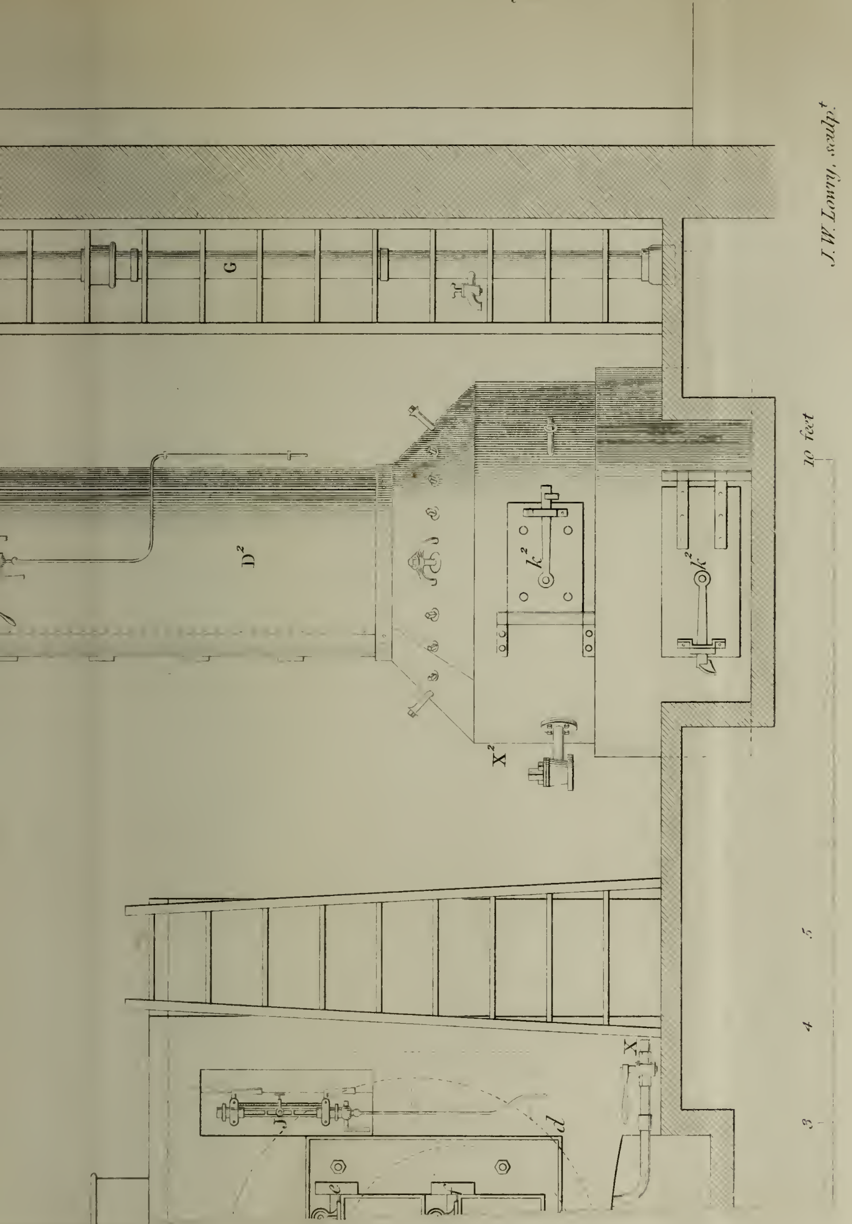


P. Stopford, delin.t

J. W. Lowry, sculp.t



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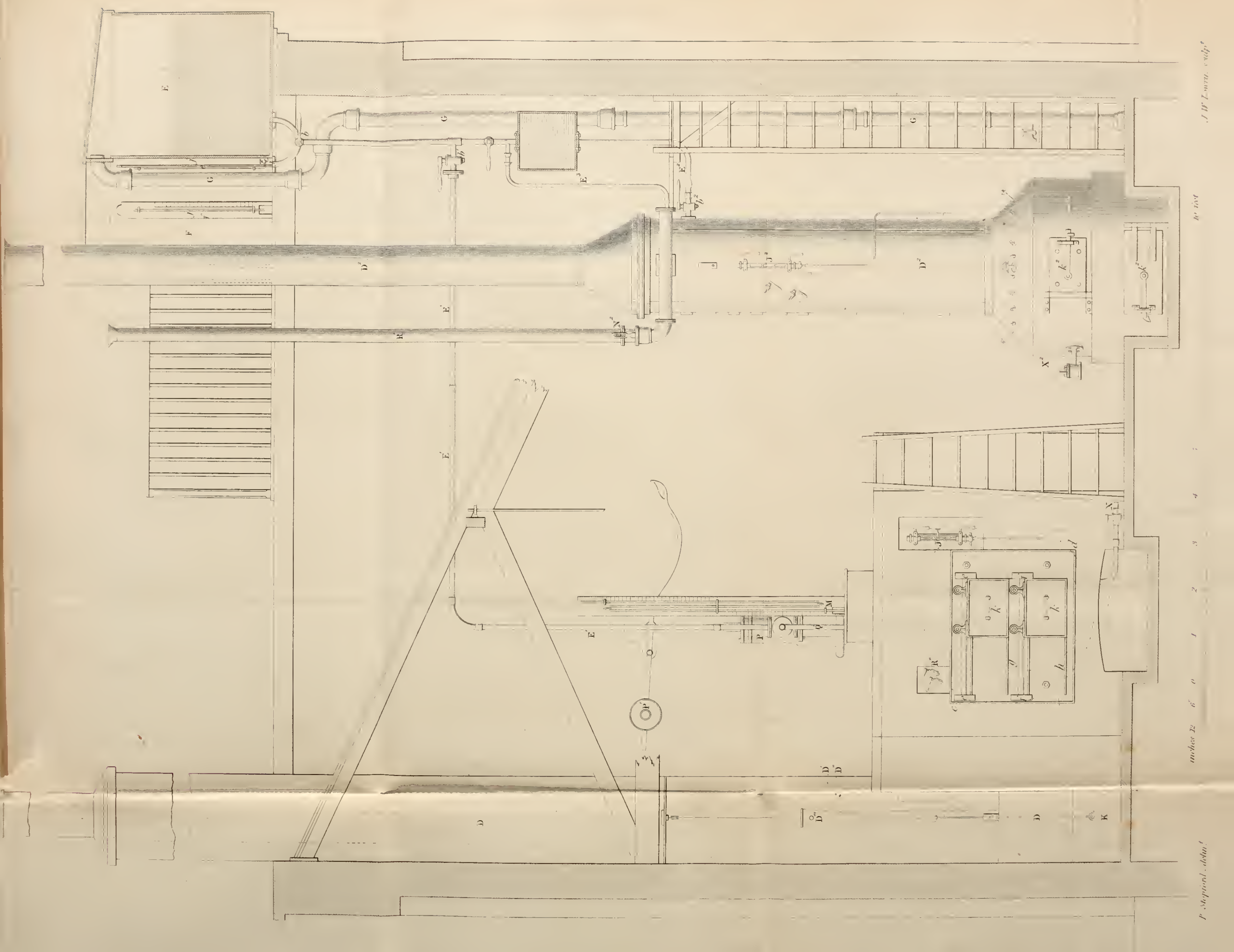
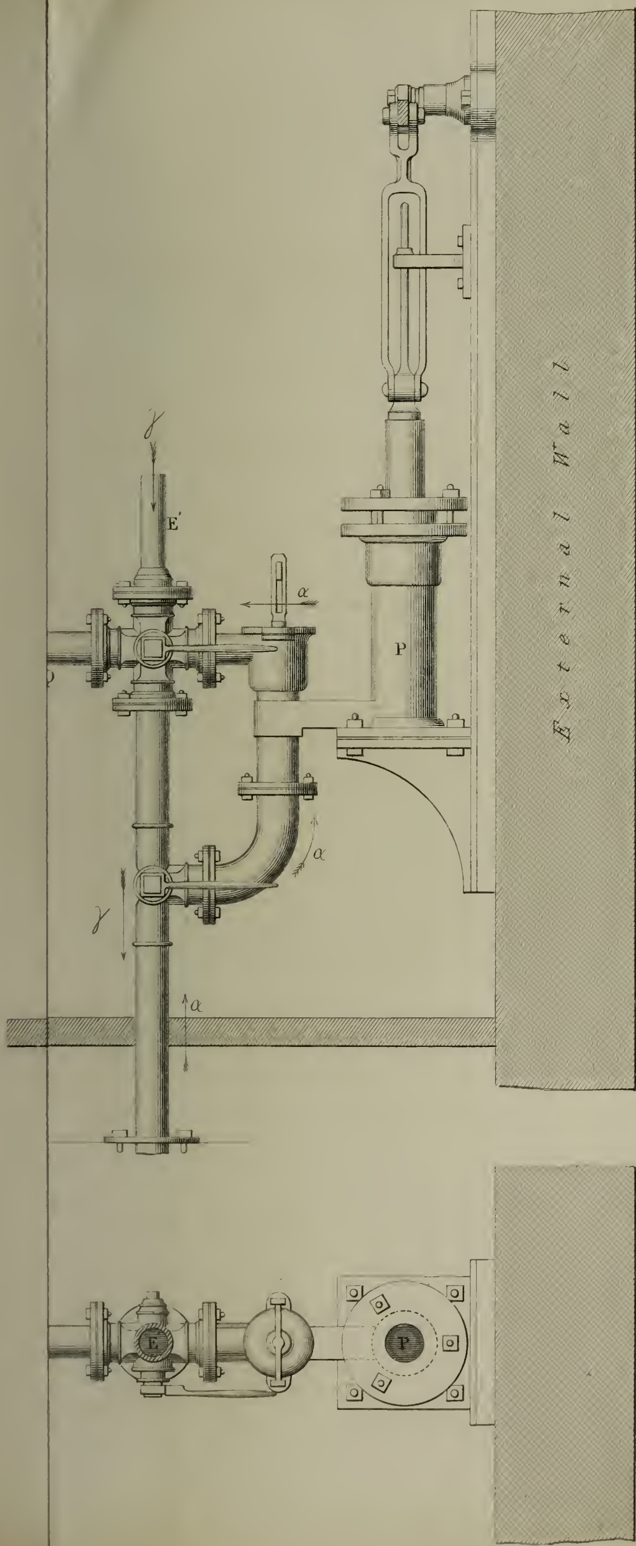
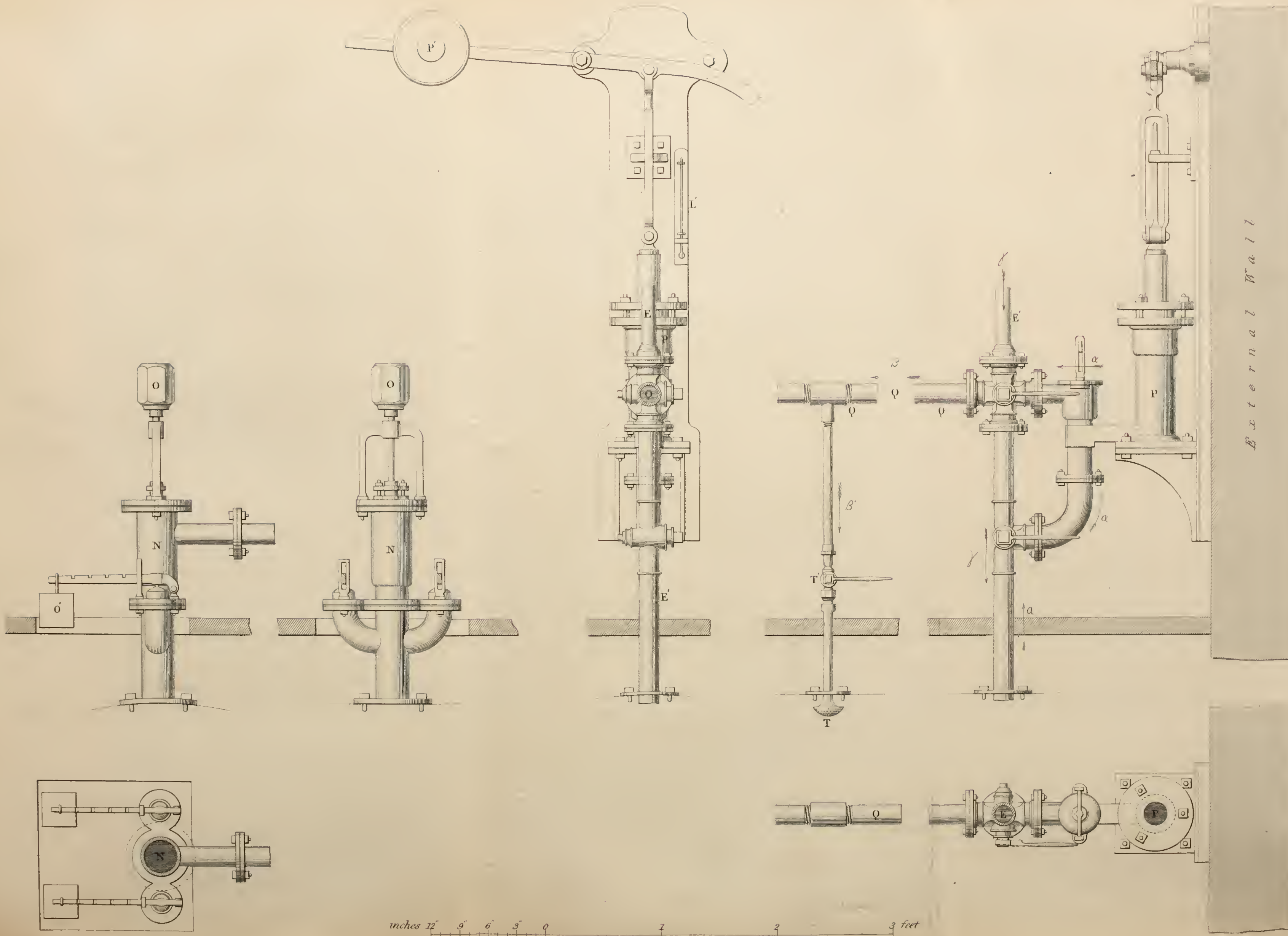


J. W. Lowry sculp.

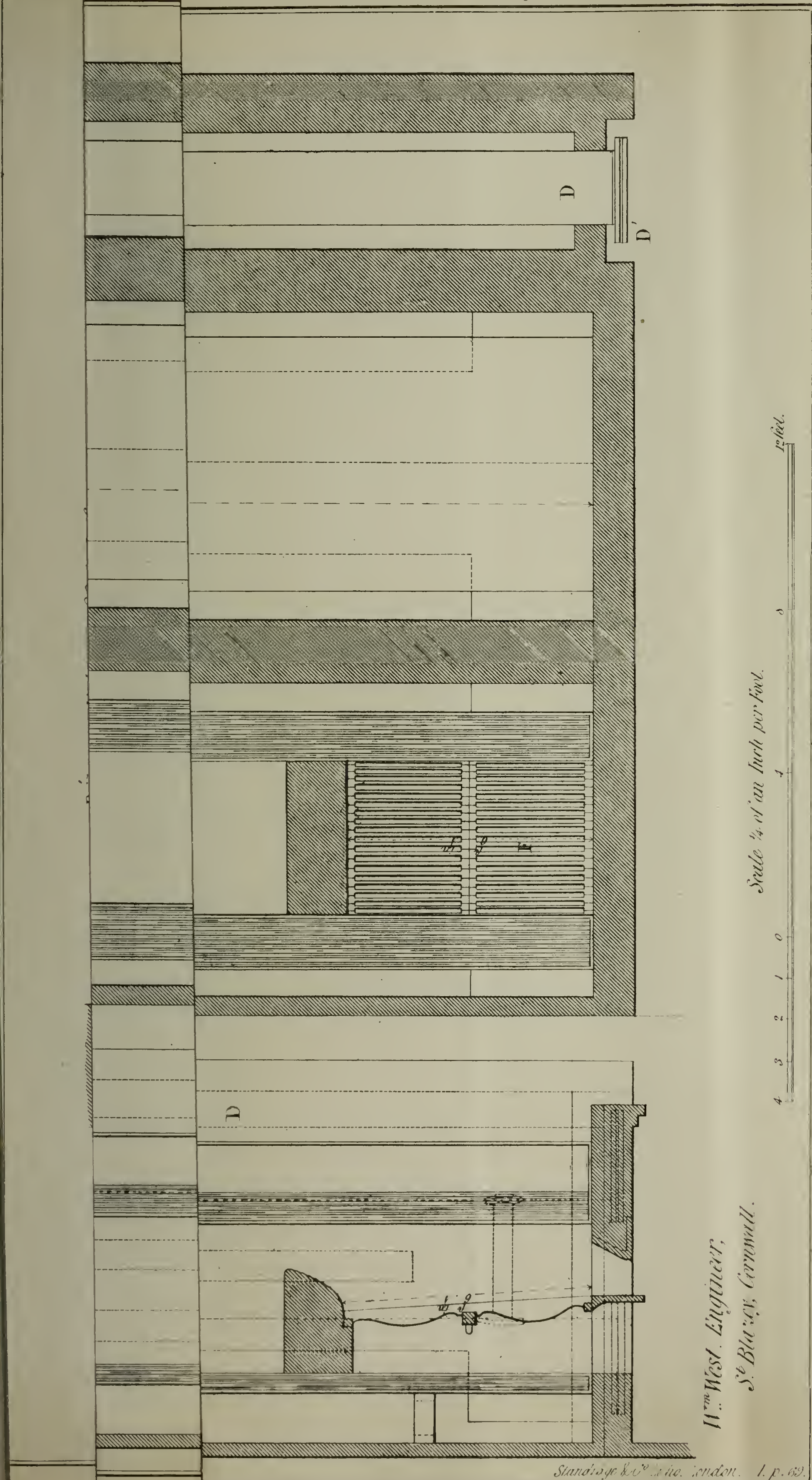


J. W. Lowry, sculp.t

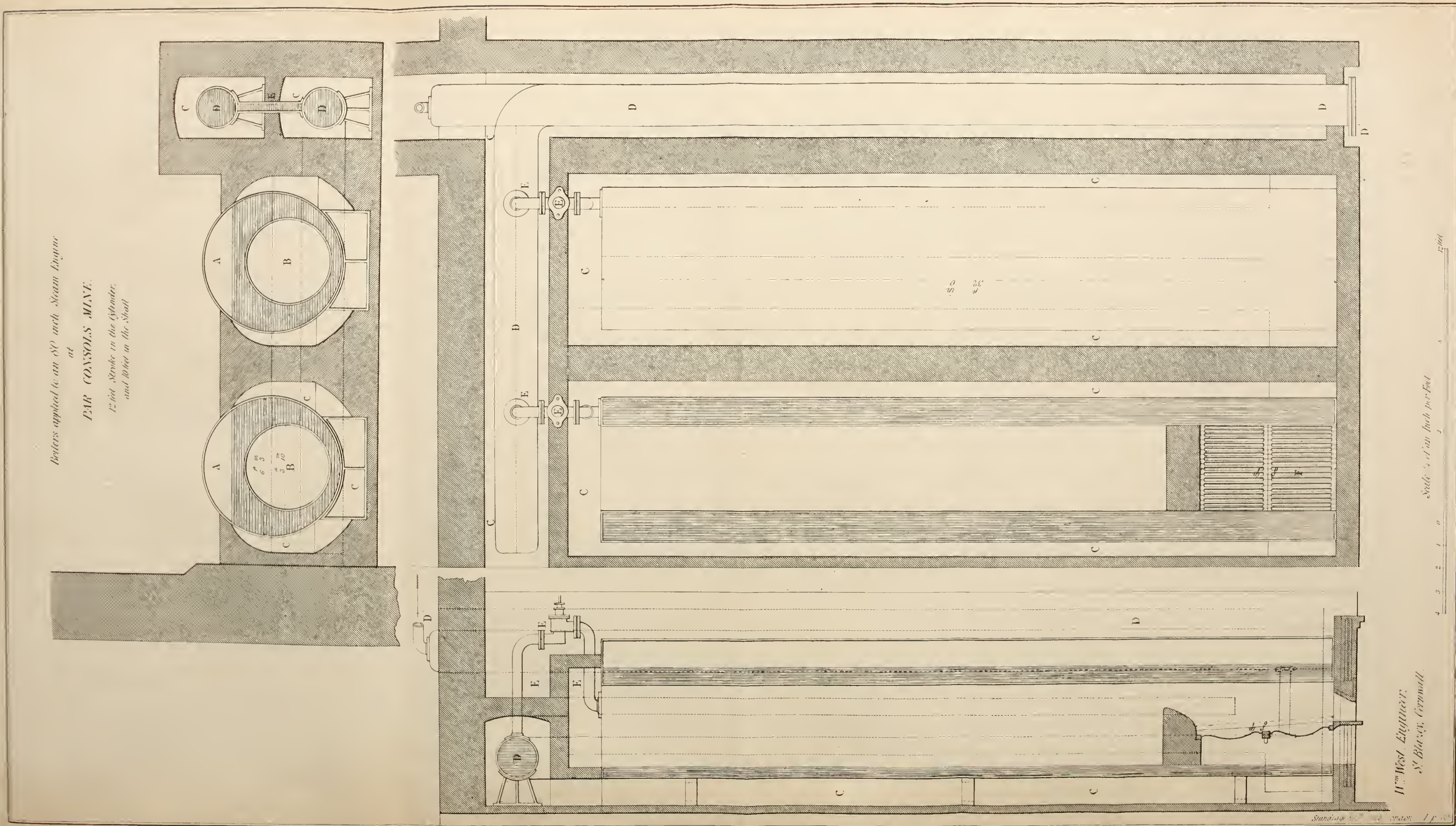


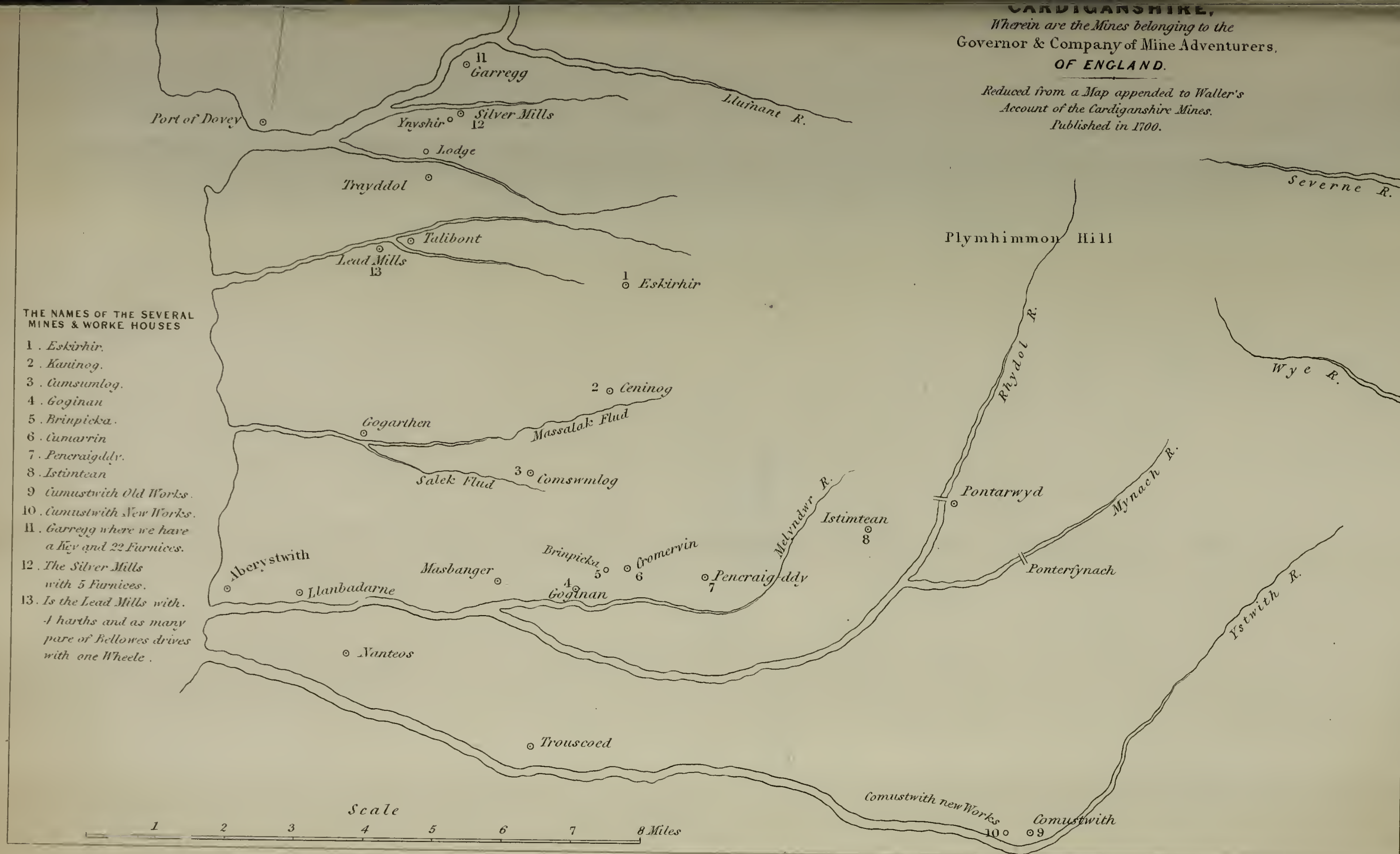
P. Stopford. delin.ᵗ

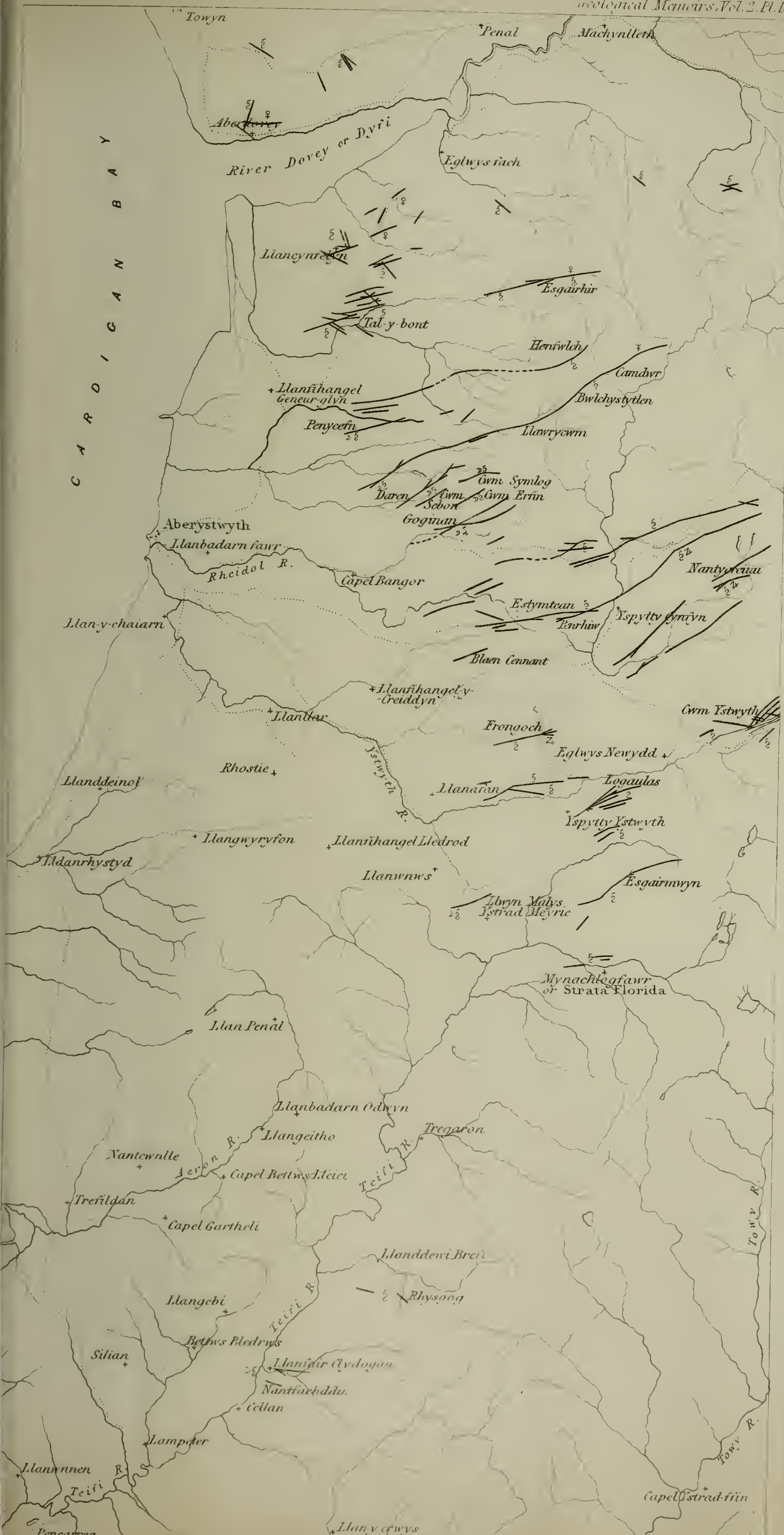
J. W. Lowry, sculp.ᵗ

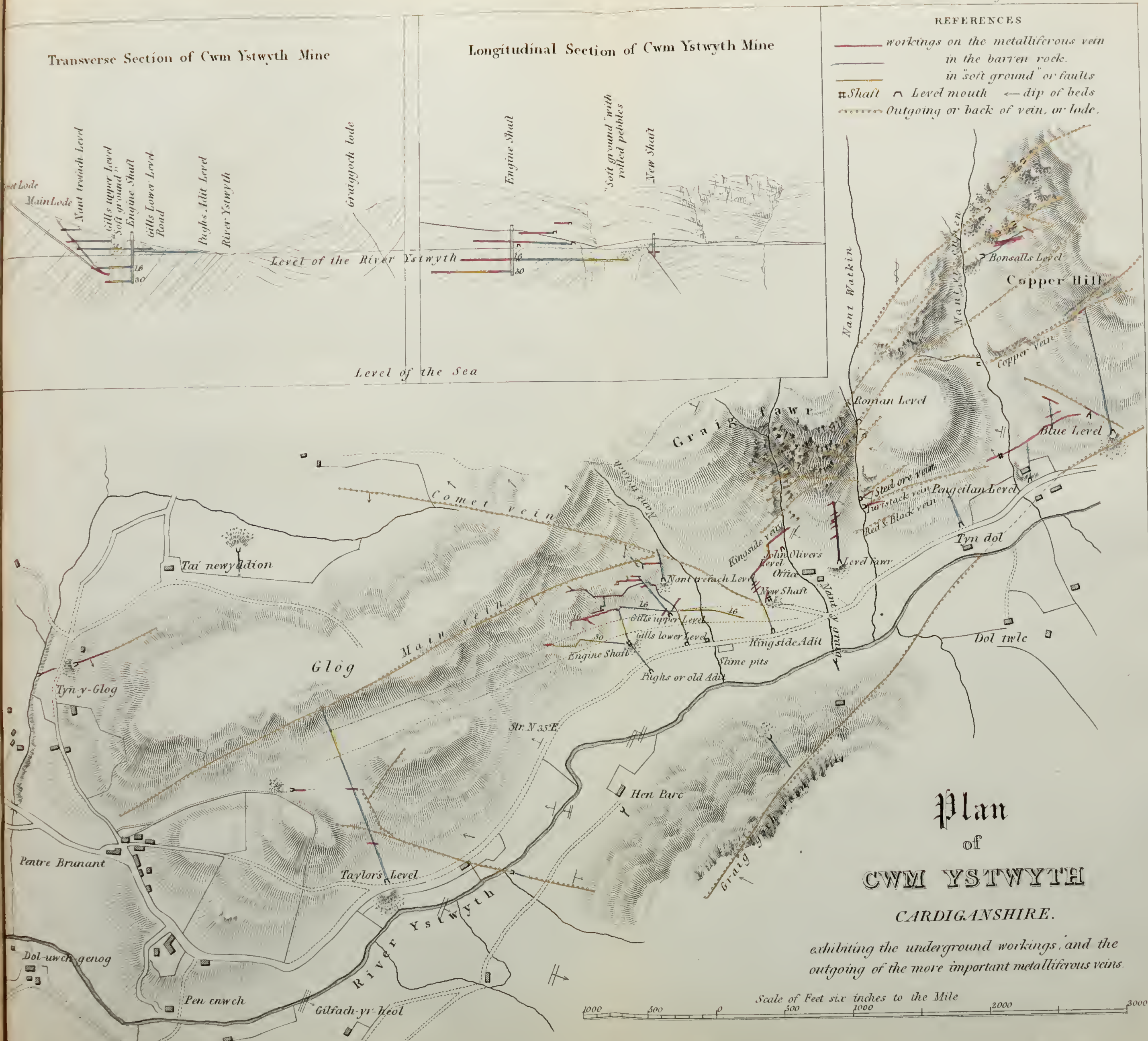


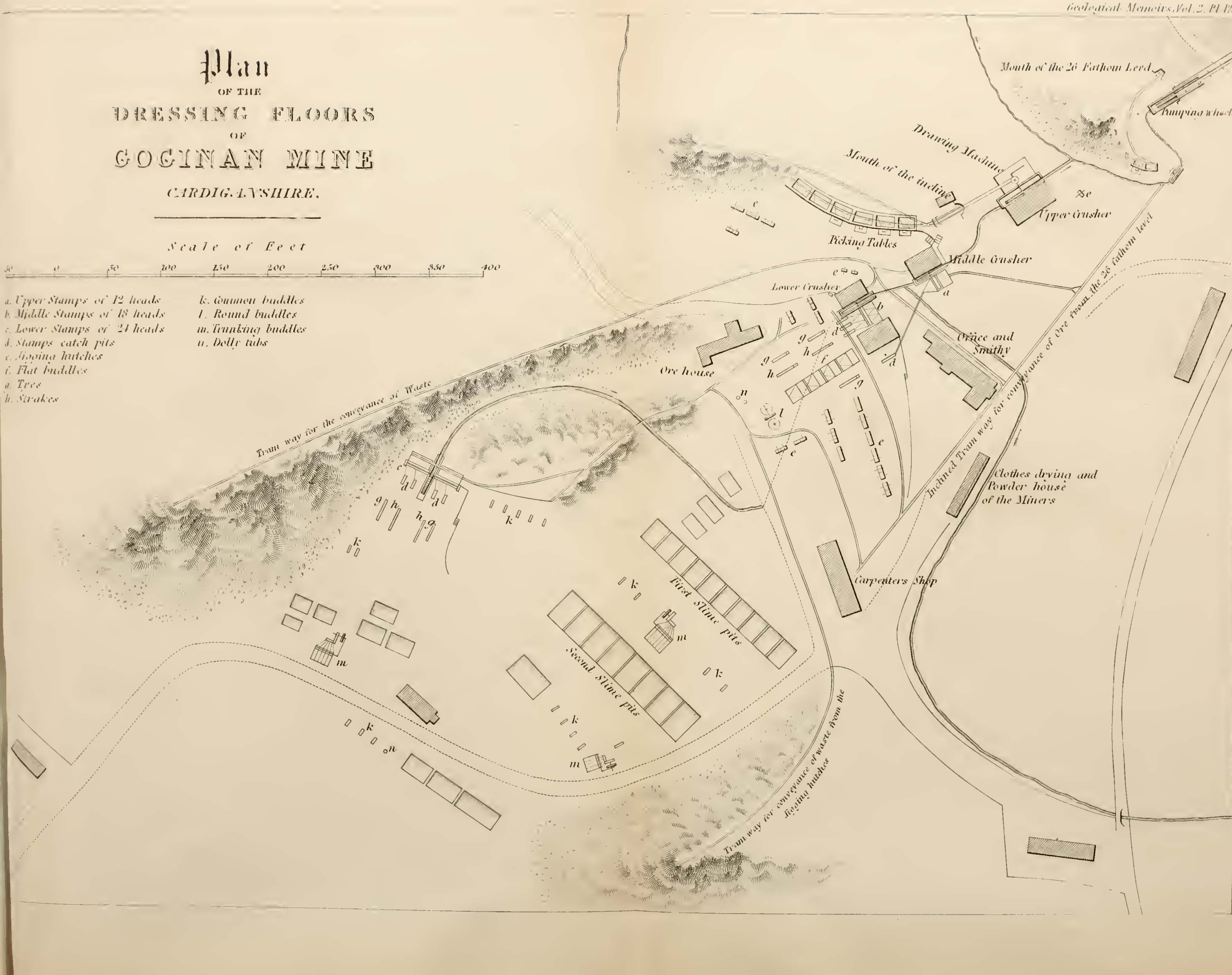
Standidge & Co. Litho. London. I. p. 69.


Boilers applied to an 80 inch Steam Engine
at
PAR CONSOLS MINE.
12 feet Stroke in the Cylinder,
and 10 feet in the Shaft
Wm West Engineer,
St Blazey, Cornwall.
Scale ¼ of an Inch per Foot


CARDIGANSHIRE,
Wherein are the Mines belonging to the
Governor & Company of Mine Adventurers,
OF ENGLAND.
Reduced from a Map appended to Waller's
Account of the Cardiganshire Mines.
Published in 1700.
THE NAMES OF THE SEVERAL MINES & WORKE HOUSES
1. Eskirhir.
2. Kaninog.
3. Cumsumlog.
4. Goginan
5. Brinpicka.
6. Cumarrin
7. Peneraigddy.
8. Istimtean
9. Cumustwith Old Works.
10. Cumustwith New Works.
11. Garregg where we have a Key and 22 Furnices.
12. The Silver Mills with 5 Furnices.
13. Is the Lead Mills with 4 harths and as many pare of Bellowes drives with one Wheele.
Port of Dovey
11 Garregg
Ynyshir
12 Silver Mills
Lodge
Trayddol
Llurnant R.
Talibont
Lead Mills 13
1 Eskirhir
2 Ceninog
Gogarthen
Massalak Flud
3 Comswmlog
Salek Flud
Aberystwith
Llanbadarne
Masbanger
Brinpicka 5
Cromervin 6
4 Goginan
Peneraigddy 7
Melyndwr R.
Istimtean 8
Nanteos
Trouscoed
Plymhimmon Hill
Rhydol R.
Pontarwyd
Mynach R.
Ponterfynach
Ystwith R.
Severne R.
Wye R.
Comustwith new Works
10
Comustwith
9
Scale
1 2 3 4 5 6 7 8 Miles


Towyn
Penal
Machynlleth
Aberdovey
River Dovey or Dyfi
CARDIGAN BAY
Eglwys fach
Llancynrelyn
Esgairhir
Tal-y-bont
Henfwlch
Camdwr
Llanfihangel
Geneur-glyn
Bwlchystytlen
Penycefn
Llawrycwm
Cwm Symlog
Daren
Cwm Sebon
Cwm Erfin
Goginan
Aberystwyth
Llanbadarn fawr
Rheidol R.
Capel Bangor
Nantyreiau
Estymtean
Penrhiw
Yspytty Cynfyn
Llan-y-chaiarn
Blaen Cennant
Llanfihangel-y-Creiddyn
Llanilar
Cwm Ystwyth
Frongoch
Eglwys Newydd
Rhostie
Llanddeinol
Ystwyth R.
Llanafan
Logaulas
Yspytty Ystwyth
Llangwyryfon
Llanfihangel Lledrod
Llanrhystyd
Llanwnws
Esgairmwyn
Llwyn Malys
Ystrad Meyric
Mynachlogfawr
or Strata Florida
Llan Penal
Llanbadarn Odwyn
Llangeitho
Tregaron
Nantcwnlle
Aeron R.
Capel Bettws Lleici
Teifi R.
Trefilan
Capel Gartheli
Towy R.
Llanddewi Brefi
Rhysgog
Llangebi
Teifi R.
Bettws Bledrws
Silian
Llanfair Clydogau
Nantfachddu
Cellan
Lampeter
Towy R.
Llanwnnen
Teifi R.
Capel Ystrad-ffin
Llan-y-crwys
Pencarreg


Transverse Section of Cwm Ystwyth Mine
Longitudinal Section of Cwm Ystwyth Mine
REFERENCES
workings on the metalliferous vein
in the barren rock.
in "soft ground" or faults
Shaft
Level mouth
dip of beds
Outgoing or back of vein, or lode.
Main Lode
Nant treiach Level
Gills upper Level
"Soft ground"
Engine Shaft
Gills Lower Level Road
Pughs Adit Level
River Ystwyth
Graiggoch lode
Level of the River Ystwyth
Engine Shaft
"Soft ground" with rolled pebbles
New Shaft
Level of the Sea
Nant Watkin
Bonsalls Level
Copper Hill
Copper vein
Roman Level
Graig fawr
Blue Level
Steel ore vein
Turistack vein
Red & Black vein
Pengeilan Level
Tyn dol
Comet vein
Kingside vein
John Olivers Level
Level fawr
Office
New Shaft
Nant treiach Level
Gills upper Level
Gills lower Level
Engine Shaft
Kingside Adit
Slime pits
Pughs or old Adit
Tai newyddion
Main vein
Glôg
Tyn y-Glog
Str. N 35 E.
Hen Parc
Dol twlc
Graig
Pentre Brunant
Taylors Level
River Ystwyth
Dol-uwch-genog
Pen cnwch
Gilfach-yr-heol
Plan of CWM YSTWYTH CARDIGANSHIRE.
exhibiting the underground workings, and the outgoing of the more important metalliferous veins.
Scale of Feet six inches to the Mile
1000
500
0
500
1000
2000
3000


Plan
OF THE
DRESSING FLOORS
OF
GOGINAN MINE
CARDIGANSHIRE.
Scale of Feet
50 0 50 100 150 200 250 300 350 400
a. Upper Stamps of 12 heads
b. Middle Stamps of 18 heads
c. Lower Stamps of 24 heads
d. Stamps catch pits
e. Jigging hutches
f. Flat buddles
g. Tyes
h. Strakes
k. Common buddles
l. Round buddles
m. Trunking buddles
n. Dolly tubs
Mouth of the 26 Fathom Level
Pumping wheel
Drawing Machine
Mouth of the incline
Upper Crusher
Picking Tables
Middle Crusher
Lower Crusher
Office and Smithy
Ore house
Tram way for the conveyance of Waste
Inclined Tram way for conveyance of Ore from the 26 fathom level
Clothes drying and Powder house of the Miners
Carpenters Shop
First Slime pits
Second Slime pits
Tram way for conveyance of waste from the Jigging hutches

MACHINERY USED IN THE DRESSING OF ORES, CARDIGANSHIRE.

The Round Buddle.

Fig. 1.

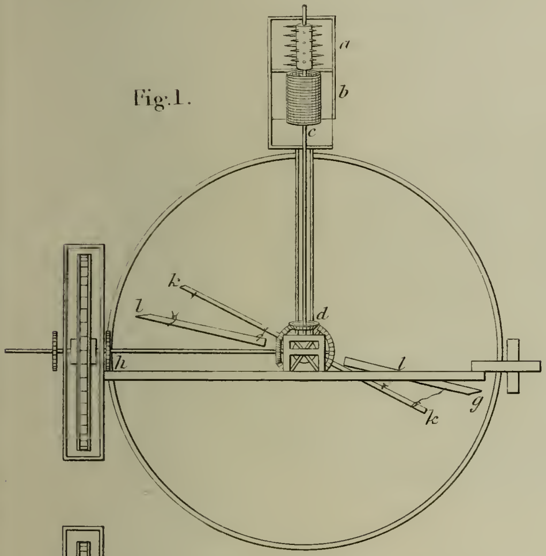
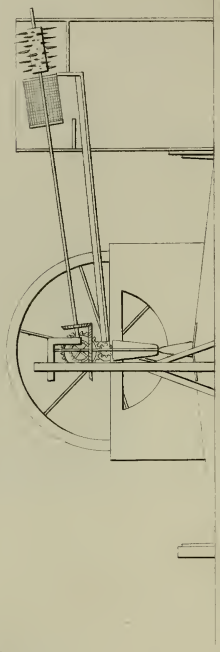


Fig. 2.



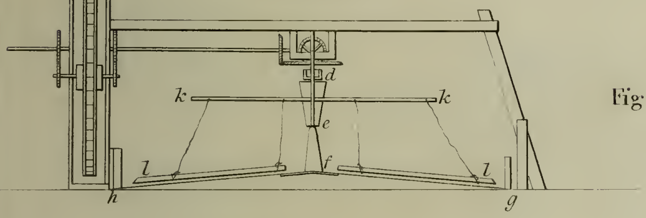


Fig. 3.

Fig. 4. The Tye.

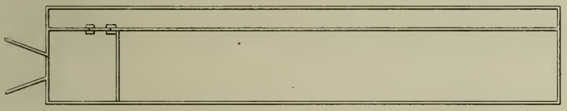
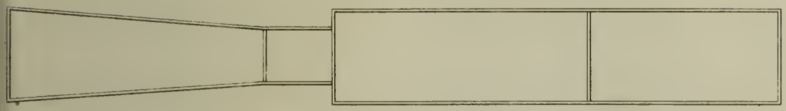


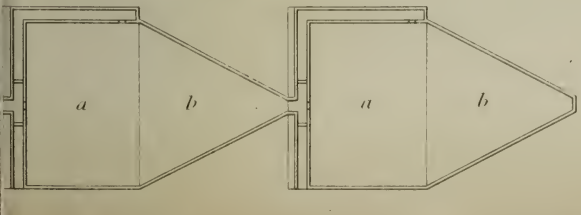
Fig. 5. The Strake.



Scale to Figs. 1. 2. 3. 4 and 5

1 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 Feet

Fig. 6. The Flat Buddle.



a Platform of boards inclined 2½ inches in 7 feet

b Catch pit, 2 feet deep

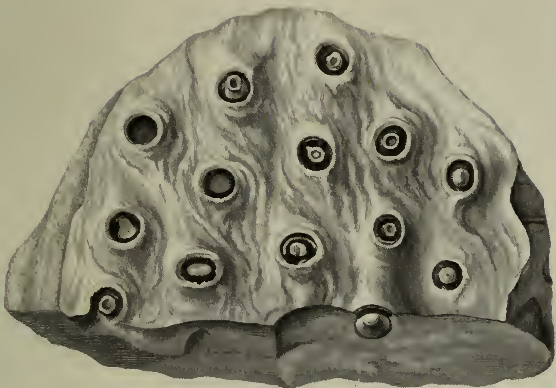
Scale of Feet

0 5 10 15 20

W. S. del. J. W. Lowry fc.

Geological Survey of the United Kingdom.

Plate 1

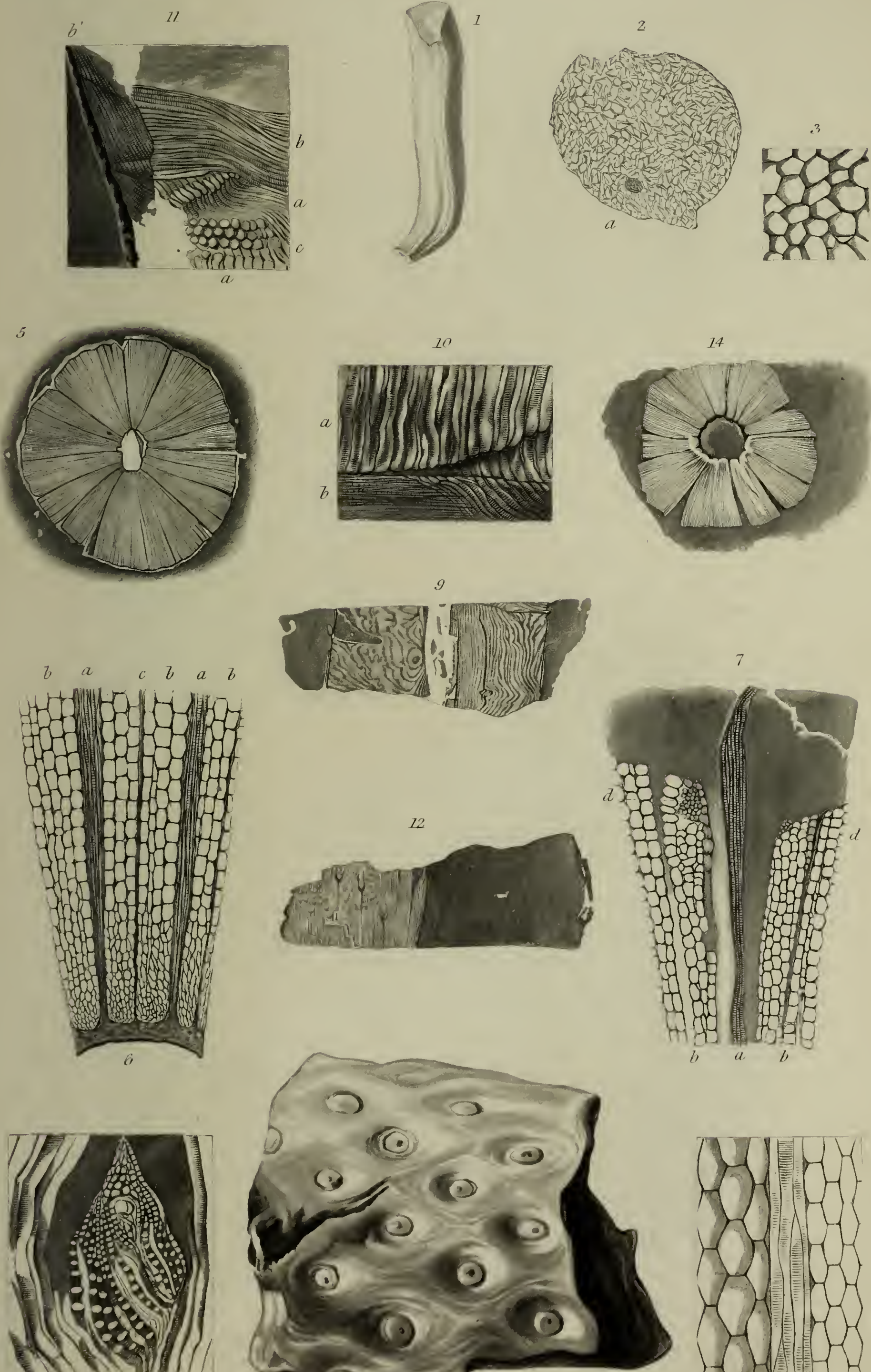


1

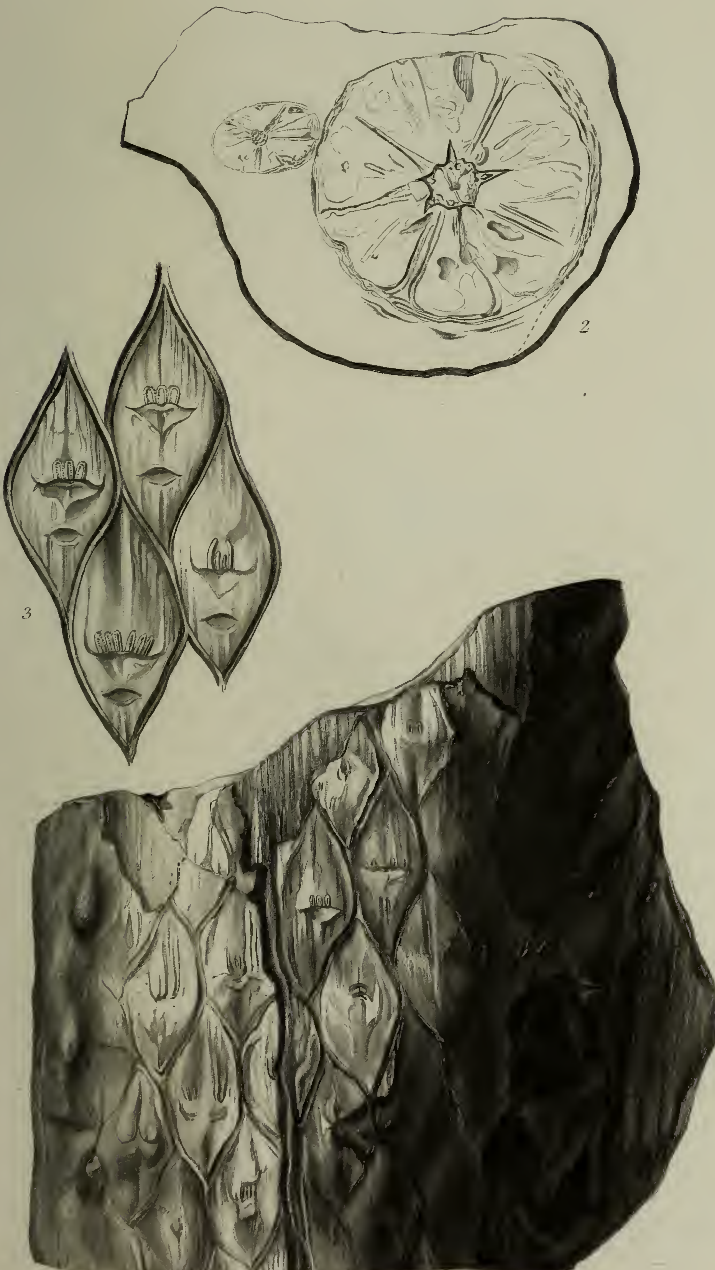
2

3

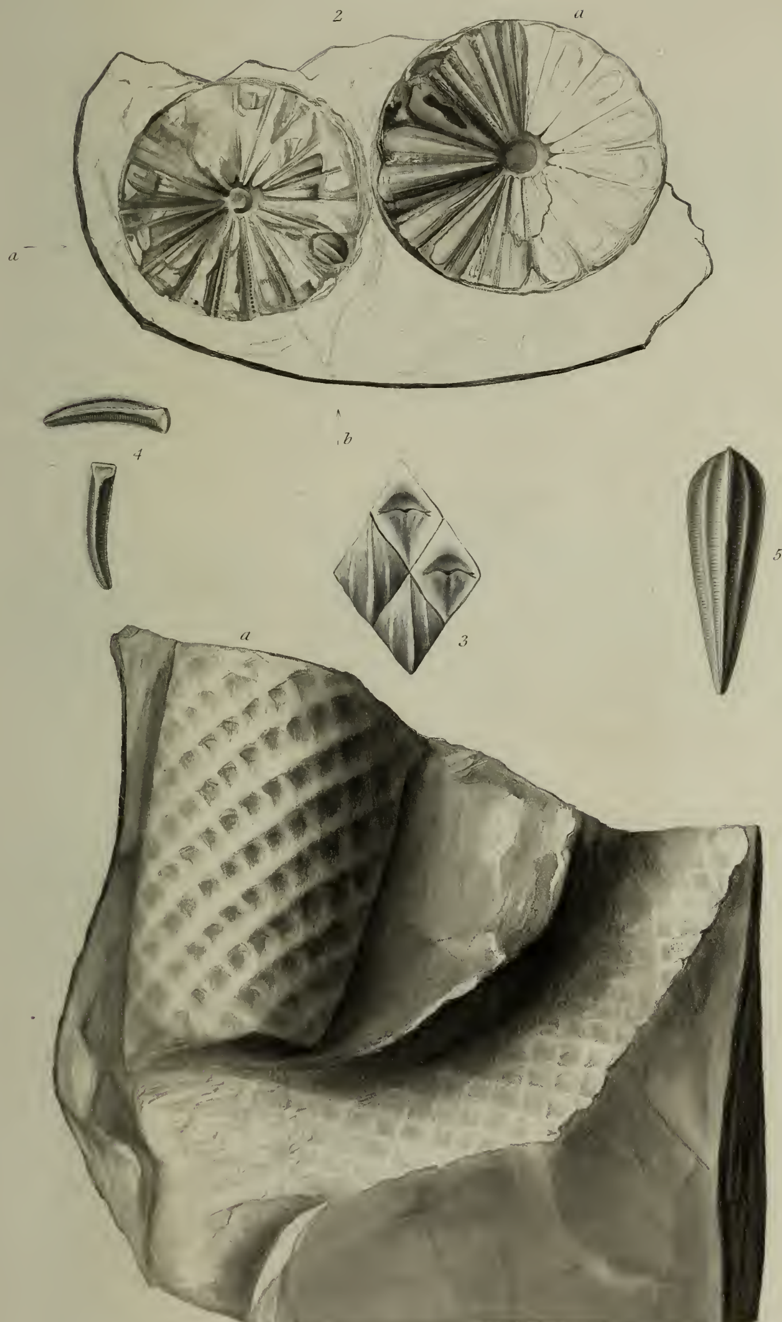
ROOTLETS of STIGMARIA.



STIGMARIA FICOIDES



LEFIDODENDRON *and* LEPIDOSTROBUS.



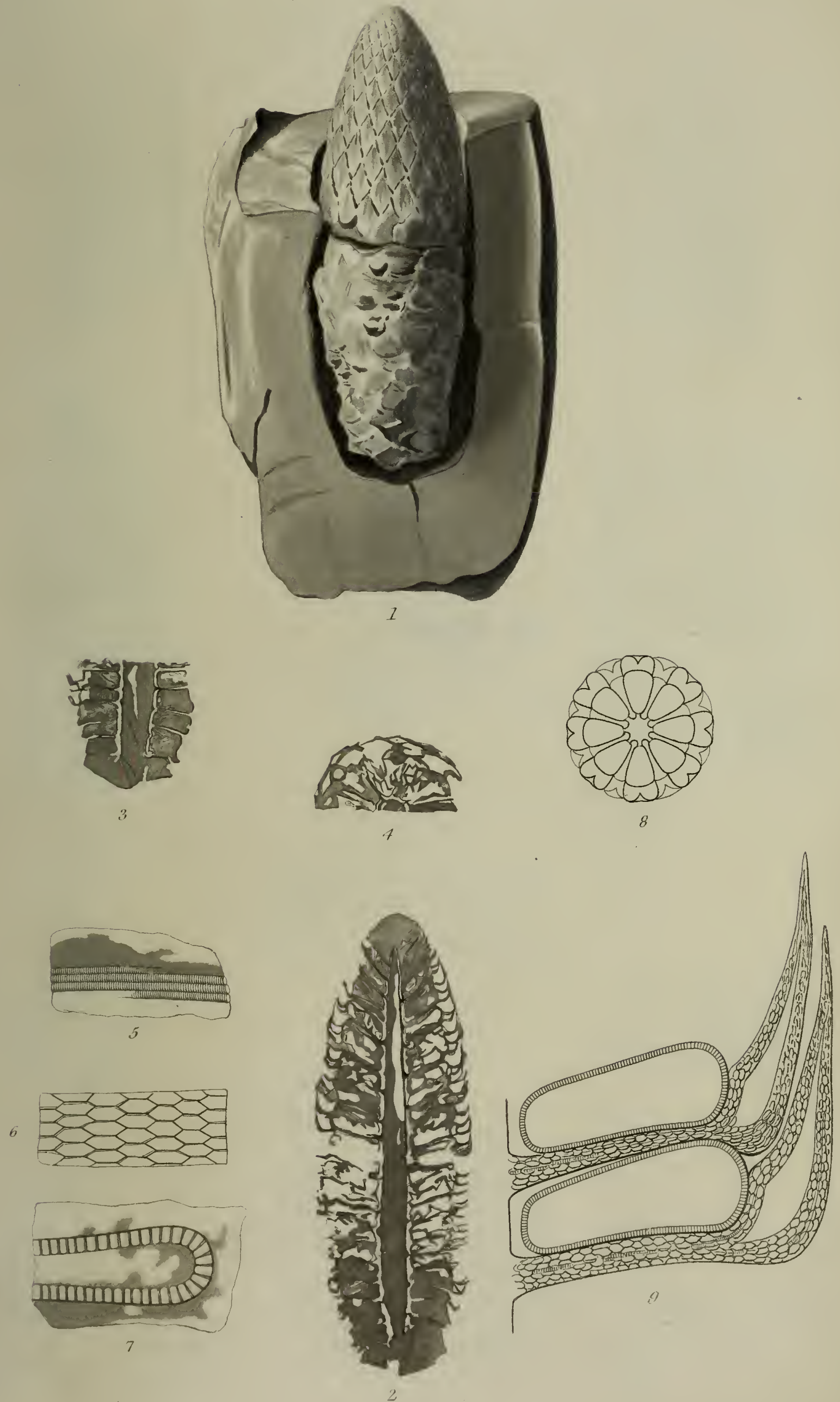
LEPIDOSTROBUS.

Geological Survey of the United Kingdom.

Plate V

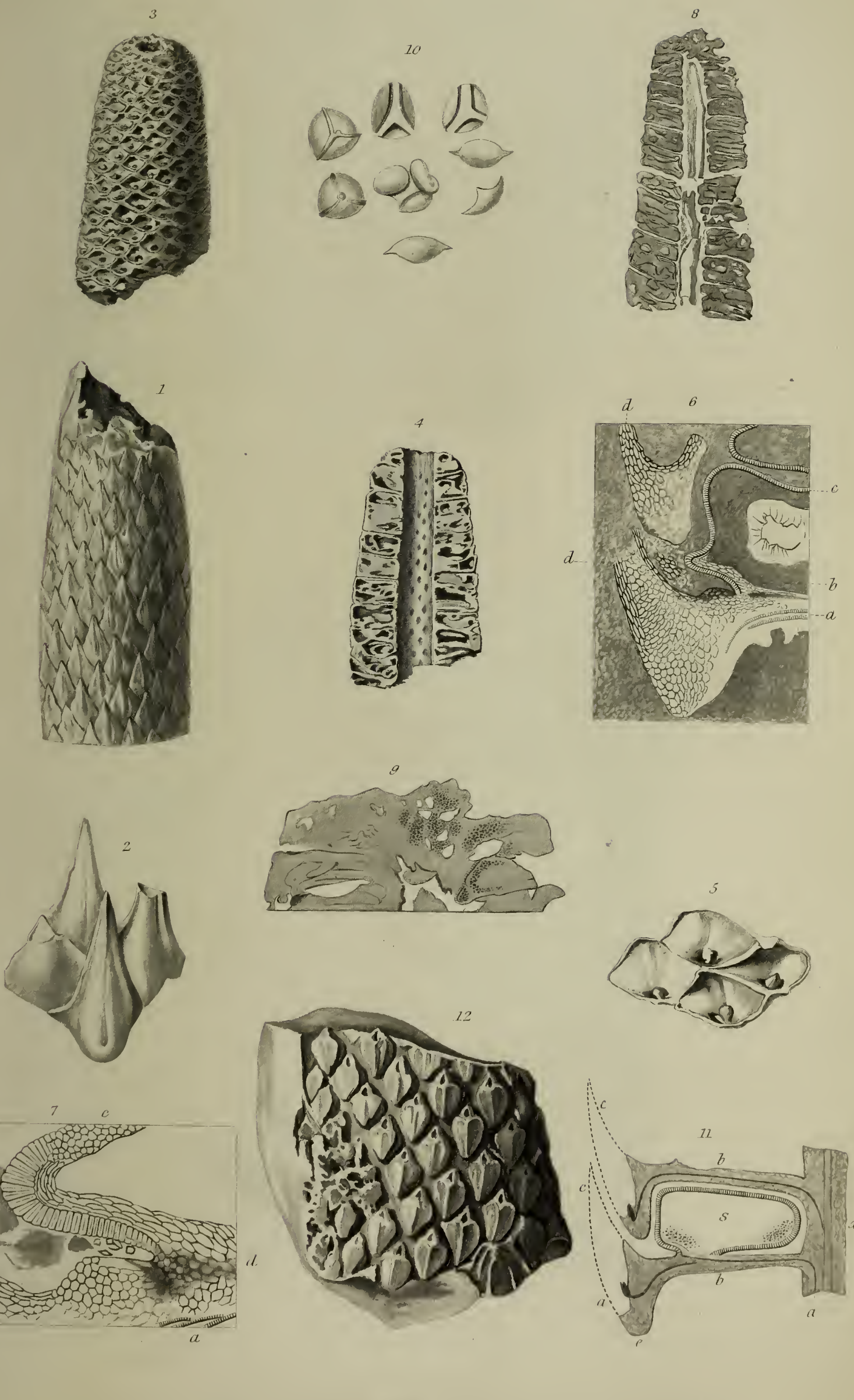
LEPIDOSTROBUS

LEPIDOSTROBUS



LEPIDOSTROBUS ORNATUS.

J. D. Hooker



LEPIDOSTROBUS ORNATUS *and* LEPIDODENDRON ELEGANS.

J. D. Hooker

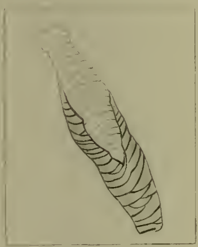
J. W. Lowry f.

1

2.

LEPIDODENDRON ELEGANS

Geological Survey of the United Kingdom.



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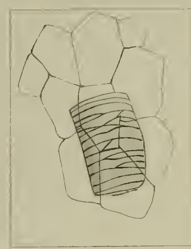

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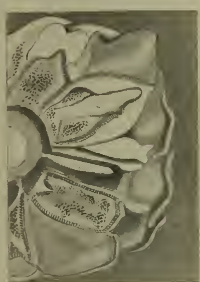

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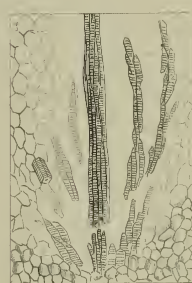

4

7

LEPIDOSTROBI *in* LEPIDODENDRON

J. D. Hooker

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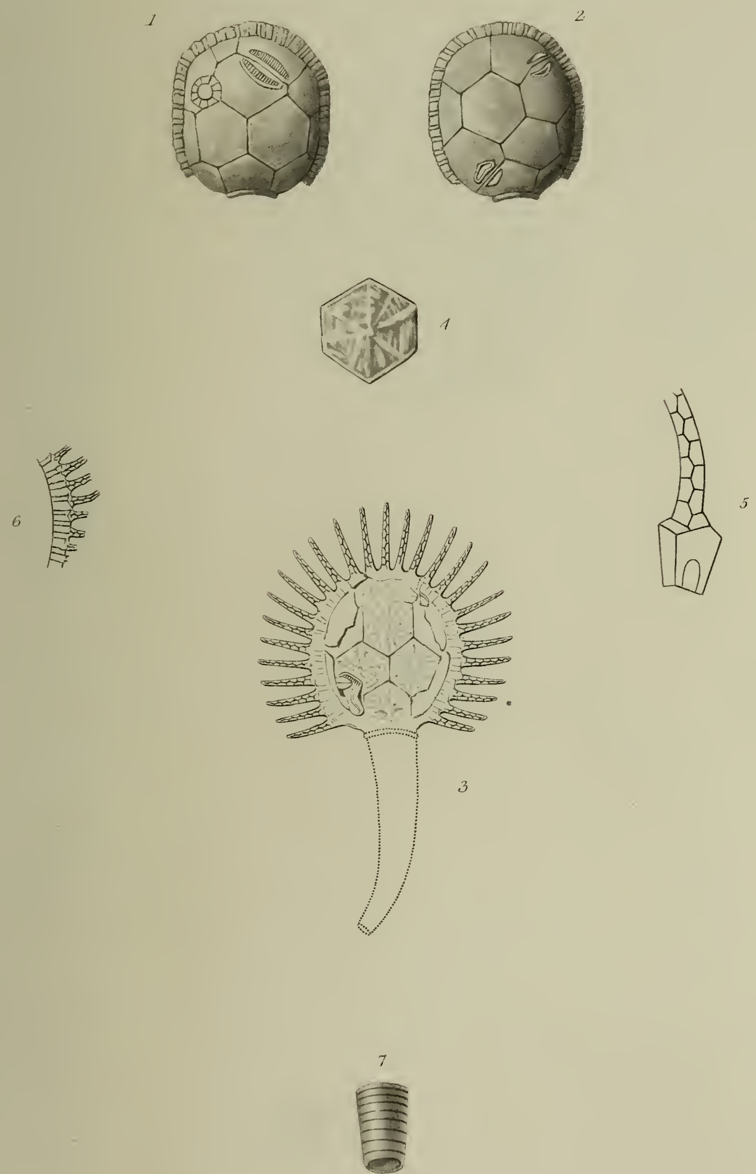
PSEUDOCRINITES
(Silurian)



PSEUDOCRINITES BIFASCIATUS *Forbes.*

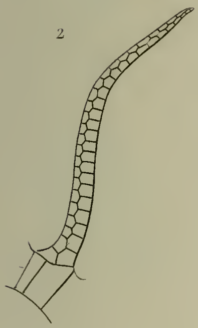
E. Forbes direx[t] J. W. Lowry fc.

Geological Survey of the United Kingdom.

PSEUDOCRINITES
(Silurian)

1

2



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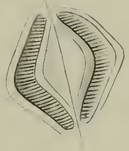

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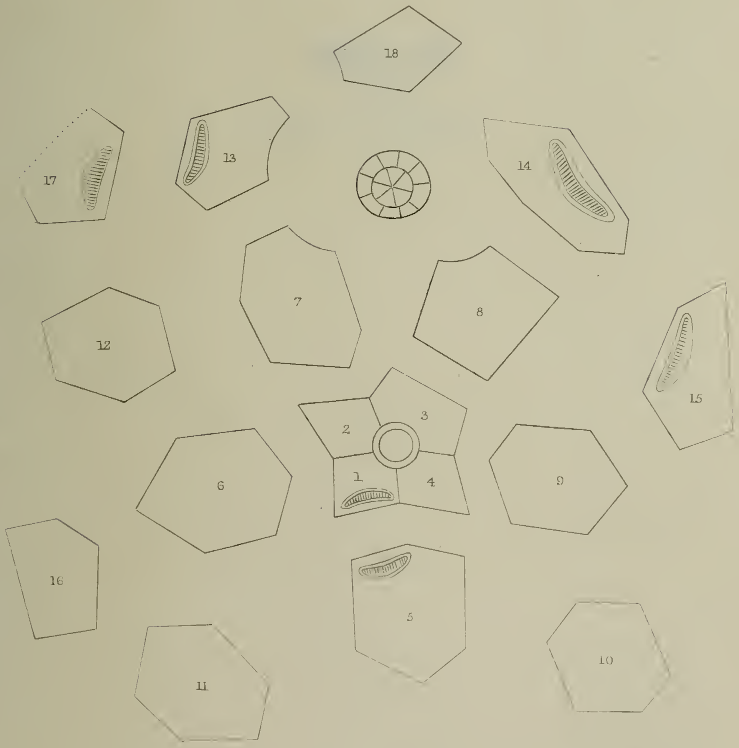
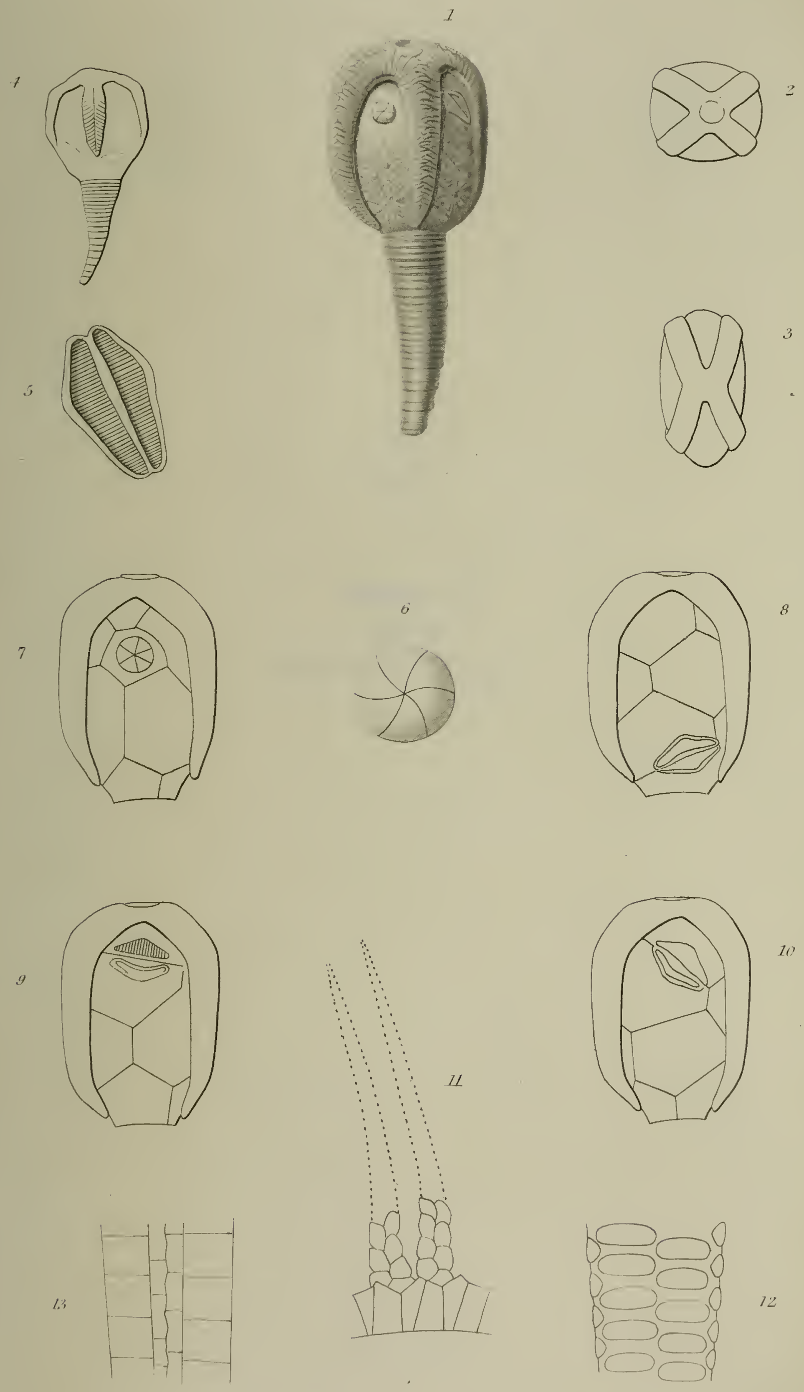


PSEUDOCRINITES MAGNIFICUS — *Forbes*

Geological Survey of the United Kingdom.

PSEUDOCRINITES
Silurian

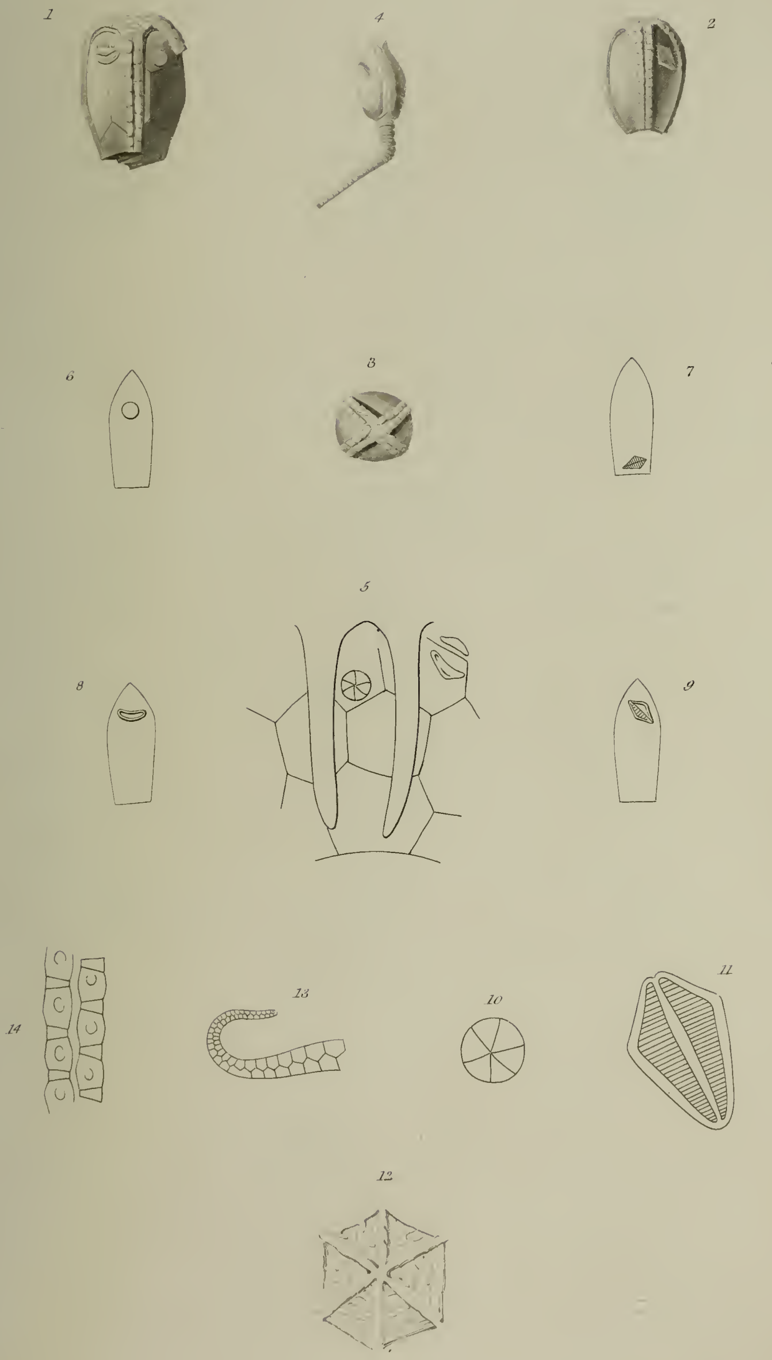


PSEUDOCRINITES QUADRIFASCIATUS *Pearce*

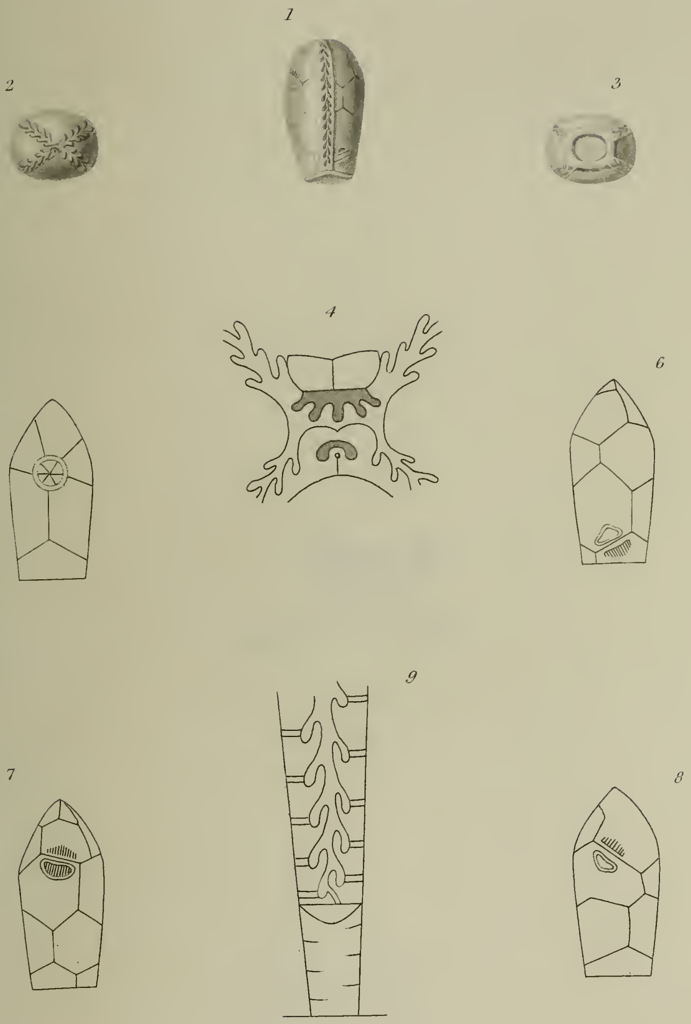
F. Forbes direx.

Geological Survey of the United Kingdom.

PSEUDOCRINITES
(Silurian)



PSEUDOCRINITES OBLONGUS *Forbes*.

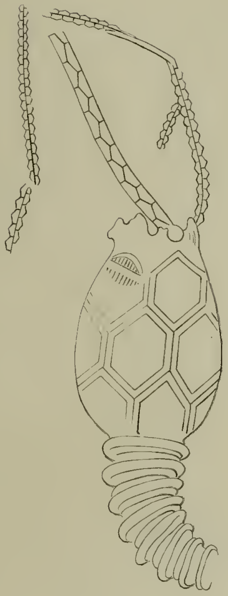


APIOCYSTITES PENTREMITOIDES *Forbes*

E. Forbes direx!

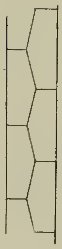
Geological Survey of the United Kingdom.

PRUNOCYSTITES
(Silurian)



2

4



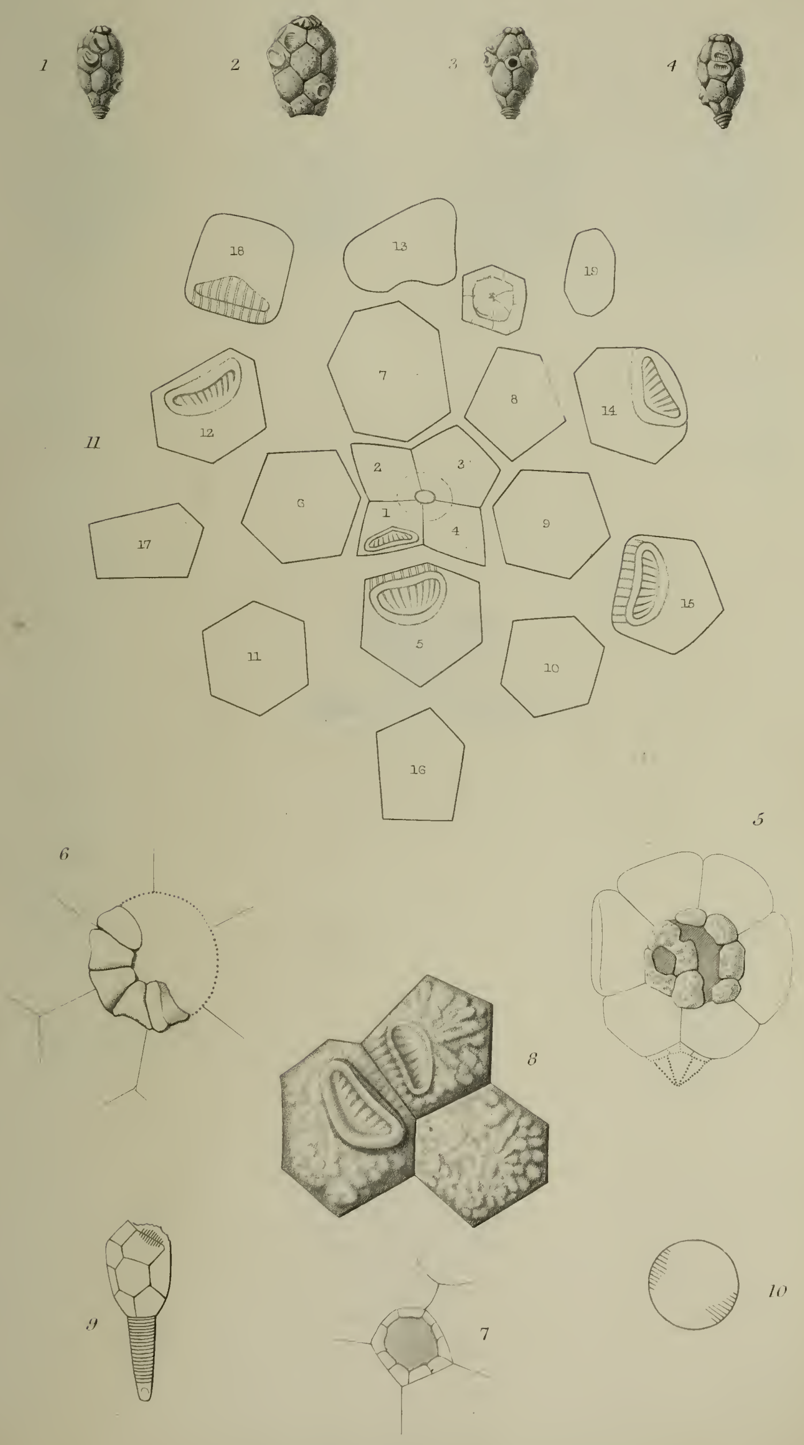
3

1

PRUNOCYSTITES FLETCHERI *Forbes*

Geological Survey of the United Kingdom.

ECHINO-ENCRINITES
(Silurian)

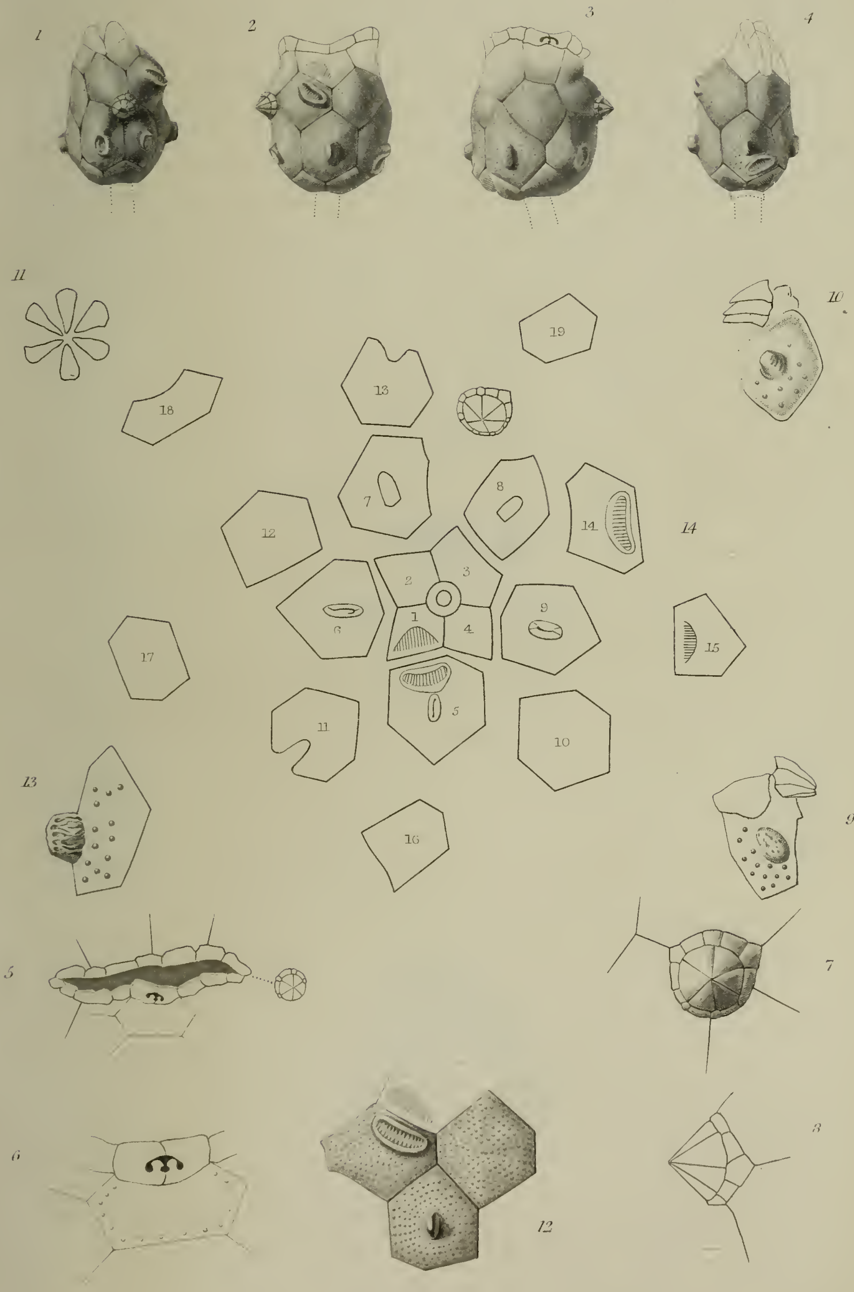


ECHINO-ENCRINITES BACCATUS *Forbes*

E. Forbes direx^t

Geological Survey of the United Kingdom

ECHINO-ENCRINITES
(Silurian)

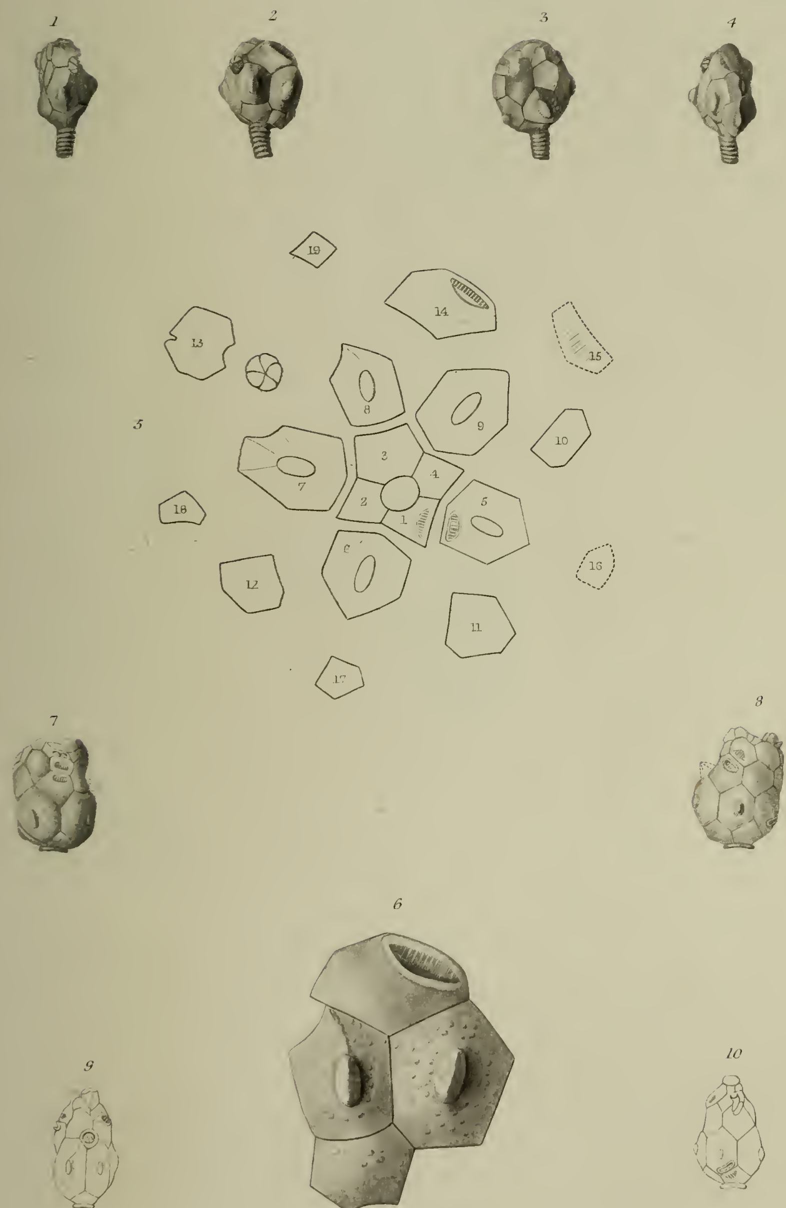


ECHINO-ENCRINITES ARMATUS *Forbes*.

del[t] E. Forbes direx[t] J.W.

Geological Survey of the United Kingdom.

ECHINO-ENCRINITES
(Silurian)

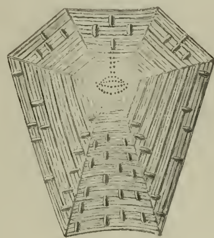


Varieties of ECHINO-ENCRINITES ARMATUS

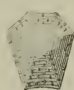
Geological Survey of the United Kingdom.

HEMICOSMITES
Silurian

1*

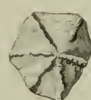


1



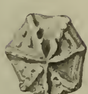
2

3



6

4



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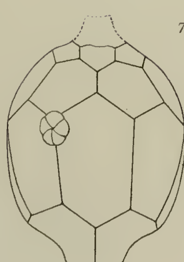
7



1 HEMICOSMITES SQUAMOSUS _ *Forbes*.

2.3.4.5 ______ PYRIFORMIS _ *Von Buch*.

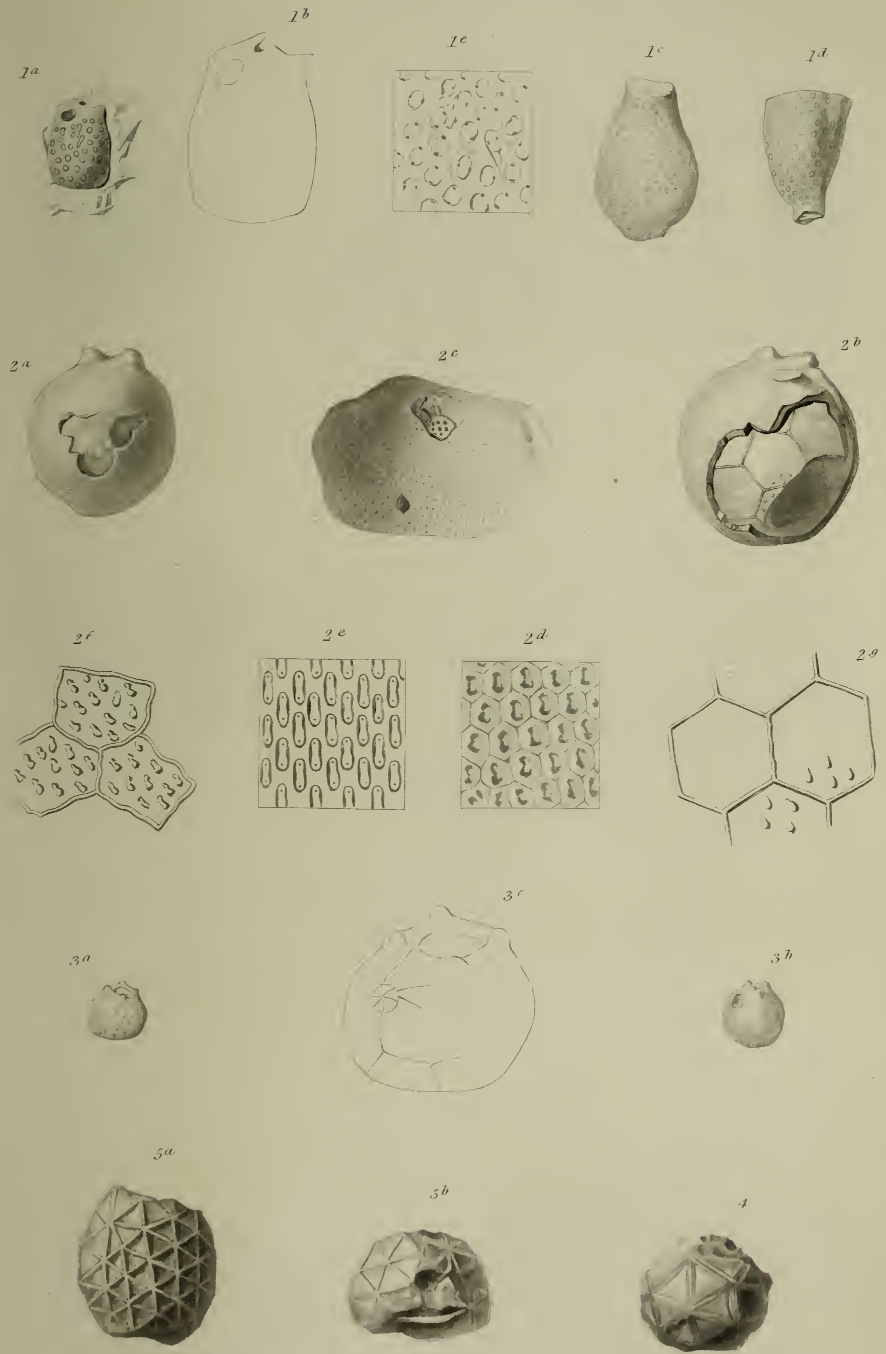
6 ______ OBLONGUS _ *Pander*.

7 *Diagram of a Hemicosmites*.

W. H. Baily del.

Geological Survey of the United Kingdom.

CARYOCYSTITES
(Silurian)



1 CARYOCYSTITES PYRIFORMIS *Forbes.* 3 — MUNITUS *Forbes*
2 — LITCHI *Forbes.* 4 — GRANATUM *Wahl.g*
5 — DAVISII *M'Coy.*

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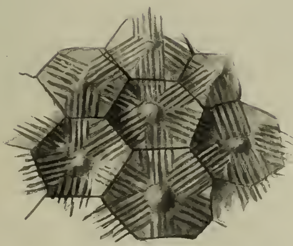
SPHŒRONITES
(Silurian)

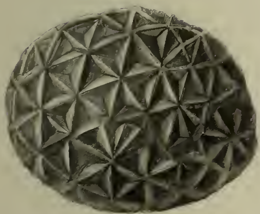
1^a

1^c



1^b

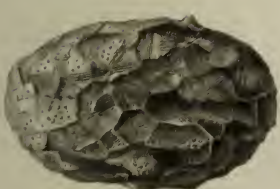
3



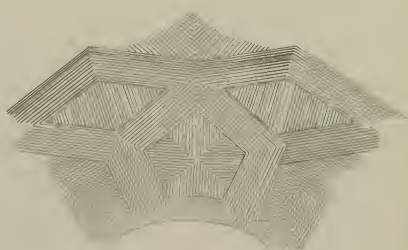
2^a

2^b

4^a



4^b



1 SPHŒRONITES AURANTIUM _Gyllenhal_ — 3 SPHŒRONITES BALTICUS _Eichwald._

2 ———— PUNCTATUS _Forbes_ — 4 ———— ARACHNOIDEUS _Forbes._

[illegible] — E. Forbes direx^t — J.W. Lowry [illegible]

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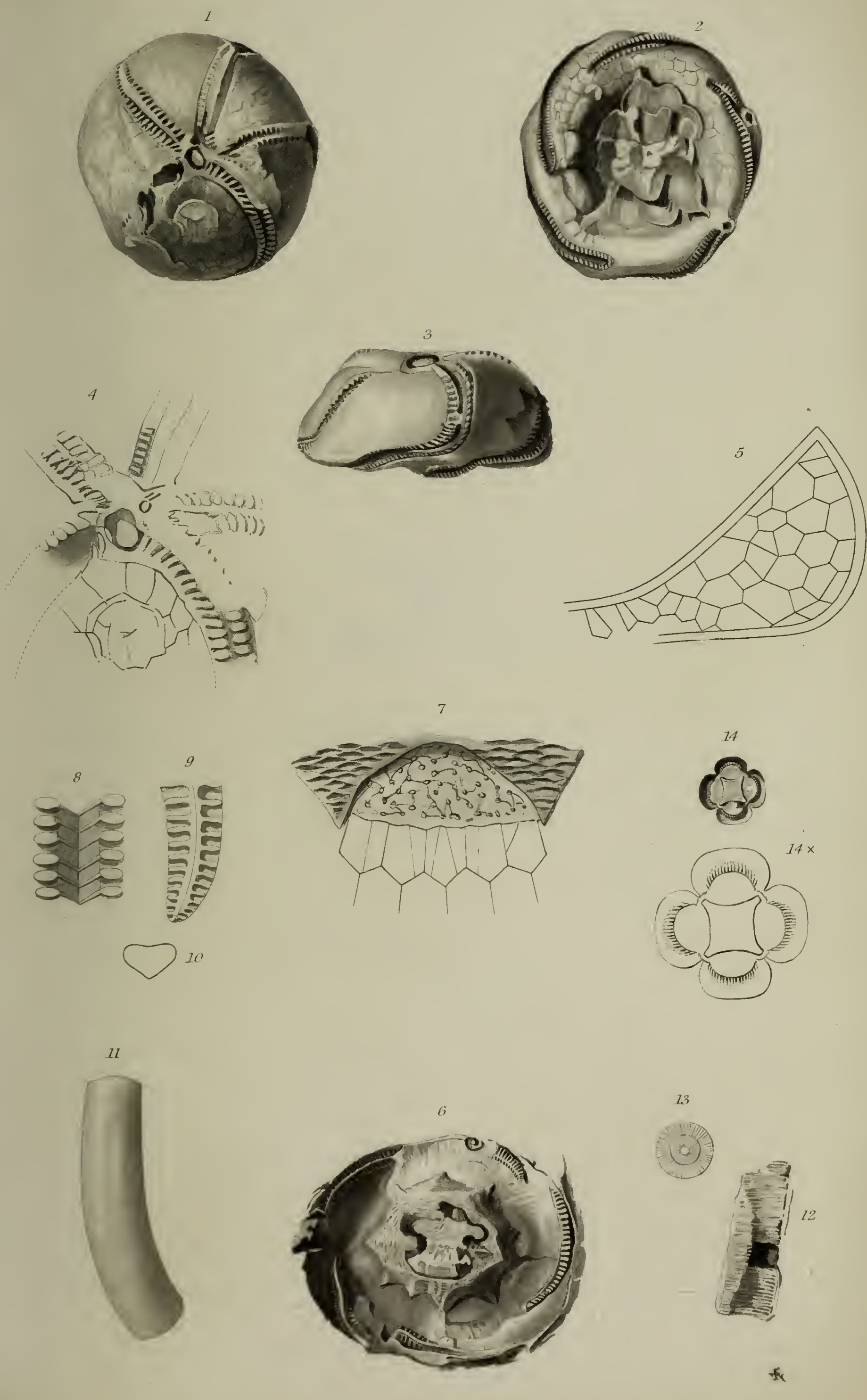
AGELACRINITES
(Silurian)



AGELACRINITES BUCHIANUS ——— *Forbes*